

**DEPARTMENT OF
CIVIL & ENVIRONMENTAL
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DRAFT VERSION

**Natural Attenuation of Hydrocarbon and
Trichloroethylene Vapors in the Subsurface
Environment at Plattsburgh Air Force Base**

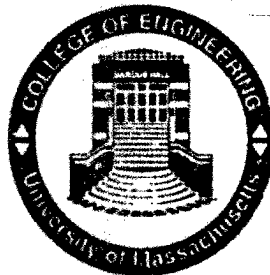
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Brooks Air Force Base
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**NATURAL ATTENUATION OF HYDROCARBON AND
TRICHLOROETHYLENE VAPORS IN THE SUBSURFACE ENVIRONMENT
AT PLATTSBURGH AIR FORCE BASE**

DRAFT VERSION-FINAL REPORT

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Report of Research Conducted for
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Civil and Environmental Engineering Department
University of Massachusetts at Amherst

26 March 1997

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EXECUTIVE SUMMARY

The Civil and Environmental Engineering Department of the University of Massachusetts at Amherst (UMASS) was contracted by the United States Air Force Center for Environmental Excellence (AFCEE) to conduct field research from 19 September 1995 to 30 September 1996 under Contract No. F41624-95-C-8012 "Surface Emissions from Jet Fuel Bioventing at Plattsburgh AFB". The work focused on bioventing of residual JP4 jet fuel and chlorinated solvents in the unsaturated zone and capillary fringe beneath Fire Training Area FT-002 at the Air Force Base in Plattsburgh, NY. **UMASS tested the hypothesis that natural attenuation processes, stimulated by injected air, reduce emissions of hydrocarbons and trichloroethylene vapors to acceptable air quality standards at the site.** Drs. David W. Ostendorf, Alan J. Lutenegger, and Sarina J. Ergas were the UMASS Principal Investigators, while Patrick Haas served as AFCEE Technical Representative for the contract. This report describes the one year effort.

The contract was performed in four tasks: unsaturated zone characterization, soil gas and solid core sampling, maximum assimilative capacity testing, and emissions testing. UMASS completed this work through detailed subtasks:

Unsaturated Zone Characterization

- Grain size distributions were measured at 108 depths from three boreholes. We determined moisture content profiles 785 samples from 24 boreholes completed during drilling trips on 9-13 October 1995, 30 November-1 December 1995, 5-7 June 1996, and 19-22 August 1996.
- We installed two thermocoupled arrays and measured soil temperature on 17 field sampling trips from 13 October 1995 to 19 December 1996, generating a data base of 377 observations.
- Stainless steel soil vapor probes were deployed in three boreholes on 11-13 October 1995 to determine ambient soil gas oxygen, total hydrocarbon, and carbon dioxide partial pressures across the unsaturated zone. Portable soil meters and a Tedlar bag sampling system were used to analyze the data from 38 depths in two of the boreholes, while a downhole oxygen sensor corroborated the profiles at 14 depths in the third borehole.
- We analyzed a separate phase sampled bailed from a recovery well by Base engineers to determine the composition of the residual JP4 jet fuel solvent liquid. A Hewlett Packard G1800A gas chromatograph with a mass spectrometer detector (GCD) was used to identify 84 alkanes, aromatics, and chlorinated hydrocarbons in the sample.
- UMASS personnel surveyed the plan location and mean sea level elevation of all probe profiles, clusters, arrays, and boreholes, for insertion into an AUTOCAD file for the project. Coordinates for all sample points are cited in Table 3.1.

Soil Gas and Solid Core Sampling

- We constructed 26 stainless steel soil gas tubing clusters to document the fate and transport of vapors through the unsaturated zone. One cluster was a control positioned well outside underlying LNAPL. The clusters were multidepth, so that 45 depths were sampled.

- The soil gas tubing clusters were sampled with portable analyzers and field installed Hewlett Packard 5890 gas chromatographs equipped with flame ionization (FID) and electron capture (ECD) detectors. We sampled soil gas oxygen, carbon dioxide, total hydrocarbons, and trichloroethylene partial pressures in Tedlar bag samples from the clusters on 17 field trips from 26 October 1995 to 19 December 1996, generating 2,083 observations.
- The vertical distribution of separate phase contamination was estimated from gas chromatographic IFD analysis of methylene chloride extracts from 785 solid core samples from 24 boreholes sampled on 9-13 October 1995, 30 November-1 December 1995, 5-7 June 1996, and 19-22 August 1996.
- The headspace of the samples was analyzed in a nitrogen glove box on line, to direct sampling efforts and delineate the contaminated interval.
- Separate phase trichloroethylene content was determined at 66 depths in six of the boreholes, using the GCD.

Maximum Assimilative Capacity Testing

- A soil venting system was installed in the center of the test area on 1 December 1995. The soil venting system injected heated air at a metered rate of 1 cfm into the capillary fringe, and included a helium tracer injection system. The soil was vented from 18 January 1996 to 9 August 1996, and a helium tracer was injected continuously from 7 February to 7 March 1996.
- We measured vented helium in 31 of the stainless steel tubing cluster sampling points on 13 February and 21 February 1996 to document the pneumatics of the soil venting. A field installed Hewlett Packard 5890 gas chromatograph with thermal conductivity detector (TCD) was used to measure the helium in Tedlar bag samples.
- An air sparging system was built in the center of the test area on 1 December 1995 as well. The air sparging system injected heated air 1.2 m below the water table from 9 August to 5 September 1996 and from 24 October to 19 December 1996. A helium tracer was injected continuously from 24 October to 24 November 1996.
- We measured helium in 35 of the stainless steel tubing cluster sampling points on 7 November and 29 November 1996, using the TCD gas chromatograph.
- A finite element model with supplemental analytical subroutines was used to model the stainless steel tubing cluster and vapor probe data. The model was tested with the helium tracer data, followed by soil gas data calibrations to determine the maximum assimilative capacity of the unsaturated zone for hydrocarbon and trichloroethylene vapor degradation. Air and total porosities were input from the moisture content data, and soil temperature was modeled with a constant diffusivity analysis.

Emissions Testing

- We installed two near surface arrays to measure helium and TCE profiles through the root zone. The arrays were of stainless steel construction, with a low sample volume facilitating sampling on 5 cm vertical spacing. Fourteen depths were established at each array.
- We analyzed helium and trichloroethylene soil gas concentrations on 20 November 1996 using field installed gas chromatographs with TCD and ECD detectors.

- We measured soil gas oxygen, total hydrocarbons, carbon dioxide, and trichloroethylene partial pressures near the capillary fringe using a soil vapor probe during air sparging. Eighty one depths were sampled in seven boreholes on 21-22 August 1996, using portable meters and a field installed FID equipped gas chromatograph.
- The near surface array data were input to an analytical model of soil gas transport through the root zone. The helium data calibrated the pneumatics, while the TCE data were used to calibrate the capacity of the root zone to assimilate TCE vapors.
- A surface isolation flux chamber was designed, built, and deployed, to verify low levels of emissions from the site area.

Conclusions

This extensive field sampling, laboratory analysis, and mathematical modeling efforts tests the hypothesis with the following result: **natural attenuation processes reduce emissions of hydrocarbon and trichloroethylene vapors to acceptable air quality standards at the site.** We support this general conclusion with particular results:

- **A significant mass of separate phase petroleum persists in and immediately below the capillary fringe.** We found total petroleum hydrocarbon levels as high as 26,400 mg TPH/kg dry soil (borehole 12AS), with contaminated intervals ranging from 1.1 to 2.54 m in extent (Table 5.6). The distribution is unimodal, and is reasonably described by capillary scaling theory (Figure 5.7). A significant fraction of the LNAPL is residually bound to the soil (as much as 7,000 mg TPH/kg dry soil). The separate phase is well correlated with the headspace concentrations.
- **Separate phase trichloroethylene occurs at levels as high as 59 mg TCE/kg dry soil immediately below the capillary fringe (Table 5.7).** The ratio of separate phase TCE to total LNAPL in 95 samples is 0.0025, yielding a separate phase mole fraction of 0.00222 and a saturated TCE vapor pressure of 170 ppm.
- **Soil gas oxygen and carbon dioxide concentrations suggest a maximum assimilative capacity of $1.4 \times 10^{-6} \text{ s}^{-1}$ under ambient conditions near the capillary fringe (Equation 5.39b).** This capacity is based on high, stoichiometrically coupled fluxes of oxygen entering and carbon dioxide leaving the fringe by ambient diffusion.
- **Soil gas oxygen and carbon dioxide concentrations suggest that soil venting increases the maximum assimilative capacity near the capillary fringe to $3.2 \times 10^{-5} \text{ s}^{-1}$ (Equation 5.67).** This capacity is based on a comparison of soil gas concentrations in study area with those observed at the control cluster.
- **We see little evidence of hydrocarbons or of hydrocarbon degradation in the unsaturated zone, although trichloroethylene exists at significant levels.** The finite element code, calibrated with tubing cluster data, suggests that trichloroethylene comprises a disproportionately high fraction of the hydrocarbon vapors found in the stainless steel tubing clusters under ambient, soil venting (Equation 5.53b), or air sparging (Equation 5.56b) conditions. The observed TCE concentrations are consistent with the saturated vapor pressure implied by Raoult's law, while the hydrocarbon pressures are two orders of magnitude lower than values expected in the absence of degradation. **These findings,**

together with the observed fluxes of oxygen and carbon dioxide, support the hypothesis that JP4 hydrocarbon vapors degrade aerobically near the capillary fringe.

- **Trichloroethylene vapors degrade in the root zone, at a maximum assimilative capacity of $2.0 \times 10^{-6} \text{ s}^{-1}$ (Equation 5.59).** This conclusion reflects calibration of quasi steady vertical transport models for abiotic helium (Equation 5.58) and first order decaying trichloroethylene (Equation 4.57) with replicated near surface array data (Tables 5.46, 5.47 and Figure 5.25). These data were gathered late in the study period, after seven months of soil venting and two months of air sparging.
- **No detectable trichloroethylene was emitted to the atmosphere.** We base this conclusion on a computed flux rate of $0.11 \text{ } \mu\text{g}/\text{m}^2\text{-min}$ (Equation 5.69b), confirmed by emissions testing at the site using the flux chamber.

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The views, opinions, and findings contained in this report are those of the Authors and do not necessarily reflect the official view or policy of the AFCEE. This report does not constitute an Air Force standard, specification, or regulation.

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LIST OF NOTATION

| Symbol | Meaning | Units |
|---------------|--|-------------------|
| b | Depth below ground surface | m |
| b_F | Depth to capillary fringe | m |
| b_L | Depth to LNAPL table | m |
| b_{LMAX} | Depth to maximum LNAPL saturation | m |
| b_M | Depth to onset of free LNAPL contamination | m |
| b_{MMIN} | Minimum depth to water table | m |
| b_R | Root zone thickness | m |
| b_W | Depth to water table | m |
| b_{WMAX} | Maximum depth to water table | m |
| b_{WMIN} | Minimum depth to water table | m |
| C | Concentration of gaseous CO_2 | kg/m^3 soil gas |
| C_S | Steady carbon dioxide concentration | kg/m^3 soil gas |
| C_{EXT} | Extract LNAPL concentration | kg/m^3 solution |
| C_{TCE} | TCE concentration in extract | kg/m^3 |
| D | Dimensionless grain size | |
| D_C | Carbon dioxide diffusivity in soil | m^2 total/s |
| D_{CS} | Steady carbon dioxide diffusivity | m^2/s |
| D_G | Hydrocarbon vapor diffusivity in soil | m^2/s |
| D_{GS} | Steady D_G | m^2/s |
| D_{HS} | Steady helium diffusivity | m^2/s |
| D_{REF} | Reference vapor diffusivity | m^2/s |
| D_T | Thermal diffusivity | m^2/s |
| D_X | Oxygen diffusivity in soil | m^2 total/s |
| D_{XS} | Steady oxygen diffusivity | m^2/s |
| d | Grain size | mm |
| d_M | Mean grain size | mm |
| F | Cumulative density function | |
| $F_{GSPARGE}$ | Spherical sparged G flux | kg/s |
| F_{IK} | Prior time step array | m^3/s |
| F_{FINE} | Fine fraction | |
| f_F | Full F_{IK} element | m^3/s |
| $F_{YSPARGE}$ | Spherical sparged Y flux | kg/s |
| G_E | G at radius of influence | kg/m^3 soil gas |
| G_F | G on source nodes | kg/m^3 soil gas |
| G_J | Nodal G value | kg/m^3 soil gas |
| G_K | Prior G value | kg/m^3 soil gas |
| G_O | Ambient source hydrocarbon concentration | kg/m^3 soil gas |
| G_S | Steady G profile | kg/m^3 soil gas |
| G_{SAT} | Saturated G | kg/m^3 soil gas |
| g | Gravitational acceleration | m/s^2 |
| H | Helium concentration | kg/m^3 soil gas |

| | | |
|-------------|---|--|
| H_F | Helium source concentration | kg/m ³ soil gas |
| H_{INJ} | Helium concentration in injection line | kg/m ³ soil gas |
| H_P | Predicted helium concentration | kg/m ³ soil gas |
| IN | Calibration curve intercept | |
| J_C | Flux of CO ₂ in the unsaturated zone | kg/total m ² -s |
| J_{GF} | Flux of G entering unsaturated zone | kg/total m ² -s |
| J_X | Flux of O ₂ in the unsaturated zone | kg/total m ² -s |
| J_{XO} | Oxygen flux into ground | μg O ₂ /total m ² -s |
| J_{YO} | TCE flux entering root zone | kg/total m ² -s |
| K_{IJ} | Transport array | m ³ /s |
| k_{ABCD} | Master element interaction | |
| M | Soil moisture content | kg moisture/kg dry soil |
| MDL | Method detection limit | |
| m_C | Molar mass of CO ₂ | kg/mole |
| m_G | Molar mass of total hydrocarbons | kg/mole |
| m_H | Molar mass of helium | kg/mole |
| m_{REF} | Reference molar mass | kg/mole |
| m_X | Molar mass of O ₂ | kg/mole |
| m_Y | Molar mass of trichloroethylene | kg/mole |
| N | Number of sample points | |
| N_D | Number of grains in volume | |
| N_P | Number of pores in volume | |
| n | Total soil porosity | m ³ pores/m ³ total |
| P | Method precision | |
| p_C | Carbon dioxide vapor pressure | Pa |
| p_G | Total hydrocarbon vapor pressure | Pa |
| p_H | Helium vapor pressure | Pa |
| p_W | Water pressure | Pa |
| p_{WM} | Water pressure at b_M | Pa |
| p_X | Oxygen vapor pressure | Pa |
| p_Y | Trichloroethylene vapor pressure | Pa |
| p_{YMDL} | MDL for TCE vapor pressure | Pa |
| p_{YPURE} | p_{YSAT} above pure TCE liquid | Pa |
| p_{YSAT} | Saturated TCE vapor pressure | Pa |
| Q | Volumetric soil gas discharge | m ³ /s |
| R_U | Universal gas constant | Pa-m ³ soil gas/mole-°K |
| RF | Gas chromatograph response factor | 1/area unit |
| r | Radial distance from well centerline | m |
| r' | Spherical distance from source | m |
| r'_F | Spherical source radius | m |
| r_M | Mean pore radius | m |
| r_P | Radius to measuring point | m |
| S | Effective total saturation | |
| S_L | Total LNAPL saturation | |

| | | |
|---------------|---|----------------------------|
| S_{LMAX} | Maximum LNAPL saturation | |
| S_{LF} | Free LNAPL saturation | |
| S_{LR} | Residual LNAPL saturation | |
| S_{LRMAX} | Maximum residual LNAPL saturation | |
| S_W | Effective water saturation | |
| S_{WMAX} | Maximum water saturation | |
| S_{WMIN} | Minimum water saturation | |
| s_G | Soil grain specific gravity | |
| T | LNAPL content | mg LNAPL/kg dry soil |
| T_{TCE} | TCE content | mg TCE/kg dry soil |
| T_{MAX} | Maximum LNAPL content | mg LNAPL/kg dry soil |
| T_{TCEMAX} | Maximum TCE content | mg TCE/kg dry soil |
| t | Time | s |
| t_{ADV} | Advective residence time | s |
| t_{DIF} | Diffusive penetration time | s |
| U | Weighting function | |
| U' | Uniformity coefficient | |
| v | Radial specific discharge component | m/s |
| v_R' | Spherical specific discharge component | m/s |
| w | Vertical specific discharge component | m/s |
| w_O | w at the ground surface | m/s |
| X | Concentration of gaseous O_2 | kg/m ³ soil gas |
| X_O | Atmospheric O_2 concentration | kg/m ³ soil gas |
| X_S | Steady oxygen concentration | kg/m ³ soil gas |
| x_{INJ} | Injection point north coordinate | feet |
| Y | Concentration of trichloroethylene vapor | kg/m ³ soil gas |
| Y_{INJ} | Injected TCE concentration | kg/m ³ soil gas |
| Y_{PURE} | Y_{SAT} for pure phase TCE | kg/m ³ soil gas |
| Y_{SAT} | Saturated TCE vapor concentration | kg/m ³ soil gas |
| y_{INJ} | Injection point east coordinate | m |
| z | Distance above the ground surface | m |
| z_O | Depth to virtual origin | m |
| α_D | van Genuchten (1980) grain size uniformity exponent | |
| α_P | van Genuchten (1980) pore size uniformity exponent | |
| β_L | Scaling factor for LNAPL retention | 1/m |
| β_W | Scaling factor for water retention | 1/m |
| χ_{TCE} | TCE mole fraction in separate phase | mole/total moles |
| Δ | Amplitude of water table fluctuation | m |
| δ_C | Carbon dioxide model error | |
| δ_D | Grain size model error | |
| δ_{DM} | Mean model error for grain size | |
| δ_G | Total hydrocarbon vapor model error | |

| | | |
|-----------------|---|--|
| δ_{GM} | Mean hydrocarbon vapor model error | |
| δ_H | Helium model error | mg/m ³ |
| δ_{HM} | Mean helium model error | mg/m ³ |
| δ_{SM} | Mean saturation model error | |
| δ_T | Temperature model error | |
| δ_{TM} | Mean model error for temperature | |
| δ_X | Oxygen model error | |
| δ_{XCM} | Mean model error for oxygen and CO ₂ | |
| δ_Y | Trichloroethylene model error | mg/m ³ |
| δ_{YM} | Mean TCE model error | mg/m ³ |
| ϵ | Thickness of free LNAPL contamination in soil | m |
| λ | Hydrocarbon vapor decay constant | s ⁻¹ |
| λ_F | Hydrocarbon decay constant in capillary fringe | s ⁻¹ |
| λ_{TCE} | TCE first order decay constant | s ⁻¹ |
| λ' | Pseudodecay constant | s ⁻¹ |
| ϕ_I | Galerkin basis function | |
| γ | Hysteretical trapping factor | |
| γ_C | Stoichiometric ratio, CO ₂ to hydrocarbons | |
| γ_X | Stoichiometric ratio, oxygen to hydrocarbons | |
| ϕ | Temperature phase shift | radians |
| θ | Air porosity | m ³ soil gas/m ³ total |
| θ_F | Irreducible volumetric moisture content | |
| θ_{LF} | Free LNAPL content | |
| θ_{LR} | Residual LNAPL content | |
| θ_W | Water porosity | m ³ water/m ³ total |
| ρ | Water density | kg/m ³ |
| ρ_B | Dry soil bulk density | kg dry soil/m ³ total |
| ρ_L | LNAPL density | kg/m ³ |
| σ_{LA} | LNAPL-air surface tension | kg/s ² |
| σ_{CM} | Error standard deviation for oxygen and CO ₂ | |
| σ_S | Error standard deviation for saturation | |
| σ_D | Error standard deviation for grain size | |
| σ_G | Error standard deviation for hydrocarbons | |
| σ_{GC} | MDL standard deviation | |
| σ_H | Error standard deviation for helium | mg/m ³ |
| σ_T | Error standard deviation for temperature | |
| σ_{WA} | Water-air surface tension | kg/s ² |
| σ_{WL} | Water-LNAPL surface tension | kg/s ² |
| σ_X | Error standard deviation for O ₂ | kg O ₂ /m ³ soil gas |
| σ_Y | Error standard deviation for TCE | mg/m ³ |
| τ | Soil gas temperature | °K |
| τ_M | Temperature fluctuation amplitude | °K |

| | | |
|-----------------|-------------------------------|--------------------|
| τ_{∞} | Averaged soil gas temperature | $^{\circ}\text{K}$ |
| ω | Annual frequency | rad/s |
| ζ | Thickness of capillary fringe | m |

1 INTRODUCTION

The Civil and Environmental Engineering Department of the University of Massachusetts at Amherst (UMASS) was contracted by the United States Air Force Center for Environmental Excellence (AFCEE) to conduct field research from 19 September 1995 to 30 September 1996 under Contract No. F41624-95-C-8012 "Surface Emissions from Jet Fuel Bioventing at Plattsburgh AFB". The work focused on bioventing of residual JP4 jet fuel and chlorinated solvents in the unsaturated zone and capillary fringe beneath Fire Training Area FT-002 at the Air Force Base in Plattsburgh, NY. **UMASS tested the hypothesis that natural attenuation processes, stimulated by injected air, reduce emissions of hydrocarbons and trichloroethylene vapors to acceptable air quality standards at the site.**

The Contract research team is comprised of:

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Section 2 of this Final Report briefly summarizes existing site assessment and remedial efforts by Base engineers, along with an account of the FT-002 area history. Background information on natural attenuation of trichloroethylene and hydrocarbon vapors and engineered systems is also included in this Section. **Section 3** discusses the methods and materials of the UMASS study in detail. Soil temperature, grain size, and moisture content methods are explained first, followed by an account of separate phase sampling, extraction, and analysis by FID gas chromatography. We present corresponding methodology for separate phase TCE measurement next, featuring a gas chromatograph with mass spectrometer. Soil gas sampling protocol is addressed next, including the design and installation of vapor probes, stainless steel tubing clusters, and near surface array. The soil gas oxygen, total hydrocarbon, carbon dioxide, TCE, and helium partial pressures from Tedlar bag samples from these points are analyzed with portable meters and gas chromatographs equipped with FID, ECD, and TCD detectors. The Section concludes with a description of the surface isolation flux chamber used to check surface emissions.

Section 4 features mathematical model derivations for soil temperature, LNAPL distribution, and soil gas fate and transport. The latter models include a finite element code with analytical subroutines for near surface fluxes. The results of the one year project are summarized in **Section 5**, including data, tests, and calibrations for:

- Soil temperature
- Grain size distribution
- Moisture content profiles
- Total separate phase hydrocarbon and TCE profiles
- Ambient, soil venting, and air sparging soil gas data
- Oxygen and carbon dioxide based estimates of aerobic degradation capacity
- Helium tracer tests for soil venting and air sparging
- TCE and total hydrocarbon transport by venting and sparging
- Root zone assimilation of trichloroethylene vapors
- Surface emissions

Some conclusions are drawn from the results of this work in **Section 6**. Raw data and references are appended to the report.

2 SITE DESCRIPTION AND BACKGROUND

2 Site Description

2.1.1 Site History and Hydrogeology

The site of the bioventing study is the former Fire Training Area denoted as FT-002 at Plattsburgh Air Force Base, Plattsburgh, New York (Figure 2.1). The Air Force Base is located in northeastern New York State, 26 miles south of the Canadian border. Bound on the east by Lake Champlain, the north by the City of Plattsburgh, and the west and south by the Town of Plattsburgh, the current Base configuration was developed in 1954. The Base covers 4795 acres, including the old military installation, housing facilities, flightline, and support areas [Parsons Engineering Science (1995)].

Fire training area FT-002 lies between 248 and 270 feet above mean sea level. Most original features of the site were altered during development of the runway and flightline in 1954. Two rivers, the Saranac and the Salmon, lie to the north and south of the base, respectively. Lake Champlain is located to the east of the base. The flow of ground water at the site is to the southeast. No surface water bodies exist at the site and ground water lies at approximately 35 feet below ground surface. There are four units that underlie site FT-002. Medium to fine grained sand extends from the surface to approximately 90 feet below ground surface. Silty sand exists at the bottom of the sand layer. A 7-foot thick clay layer exists on the eastern side of the site. A 30 to 40 foot thick clay/till layer exists at approximately 80 to 105 feet below ground surface. The clay layer is underlain by limestone bedrock at approximately 120 feet below ground surface.

Three distinct ground water units exist below the site. A shallow unconfined aquifer is present at approximately 35 feet below ground surface. A series of aquitards and aquicludes exists within the network of clay lenses and glacial till. The third unit is a confined bedrock aquifer. The average ground water gradient at the site is 0.010 ft/ft. Ground water fluctuations of about 4-5 feet occur due to seasonal variations. In situ, hydraulic conductivity measurements at the site ranged from 0.059 to 90.7 ft/day, with the average determined to be 11.6 ft/day. Relationships between in situ values and those determined through empirical grain size data (8.49 to 84.9 ft/day) agreed well with these values. Effective porosity at the site has been assumed to be 0.30 by Base engineers.

The study area is located in the northeast corner of the Base, 150 m west of the runway and 150 m east of the western boundary. It is also bordered on the north by domestic waste/spent munitions landfill LF-023 and to the south by domestic waste landfill LF-022. Fire training area FT-002 was used to train fire fighting personnel from the mid to late 1950's until the facility was closed in May 1989. The pits were unlined until 1980 when two of the pits, designated 1 and 2, were modified with cement stabilized soil liners. Pits 1 and 4 had been removed from service at this point. Previous investigations have indicated that four unlined fire pits existed at the site and were filled with off-spec JP-4 jet fuel mixed with waste oil, solvents, and other miscellaneous chemicals before being set on fire as training exercises. Soil and ground water beneath the pits

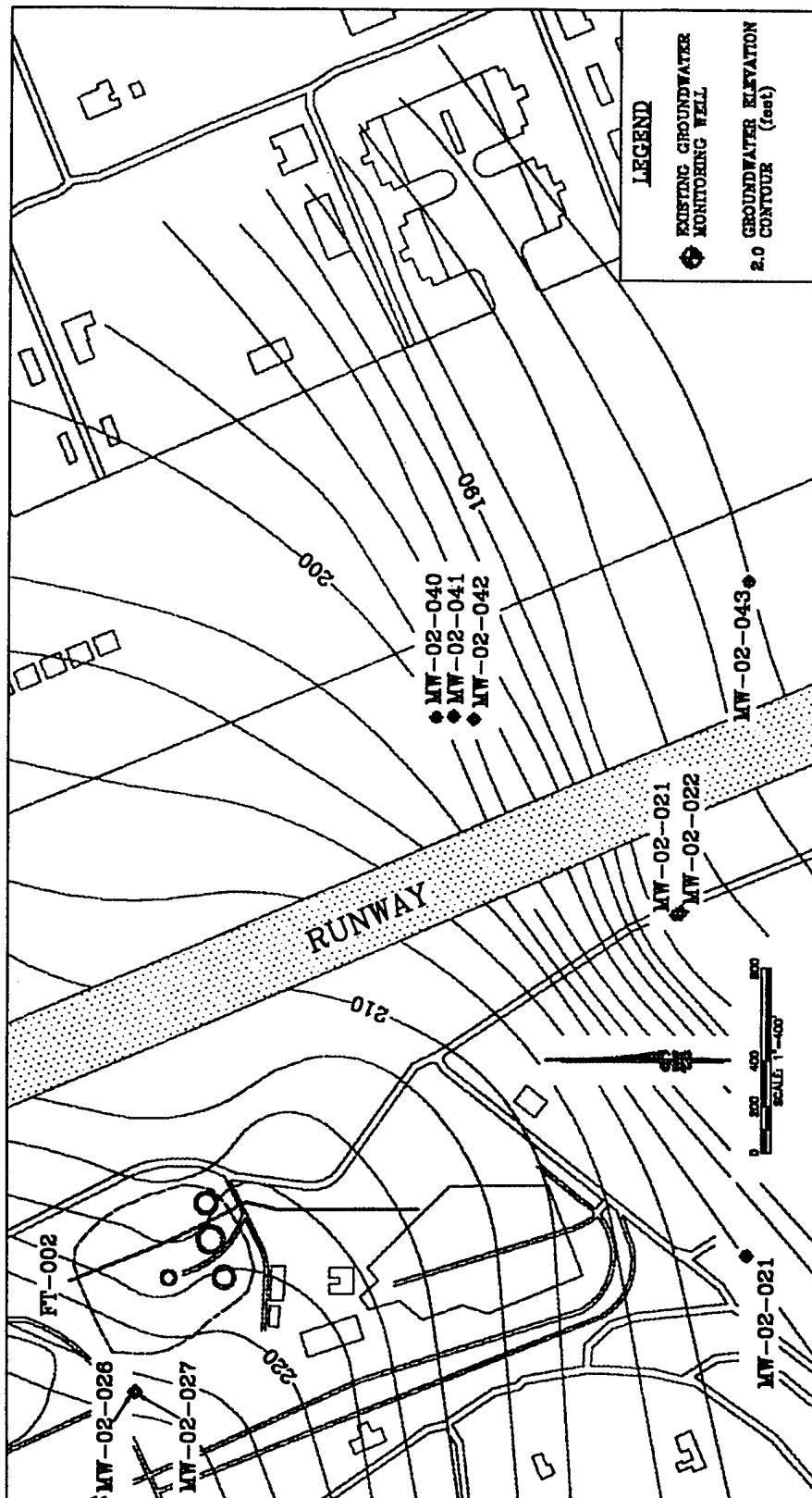


Figure 2.1a Site Plan: Plattsburgh Air Force Base Runway

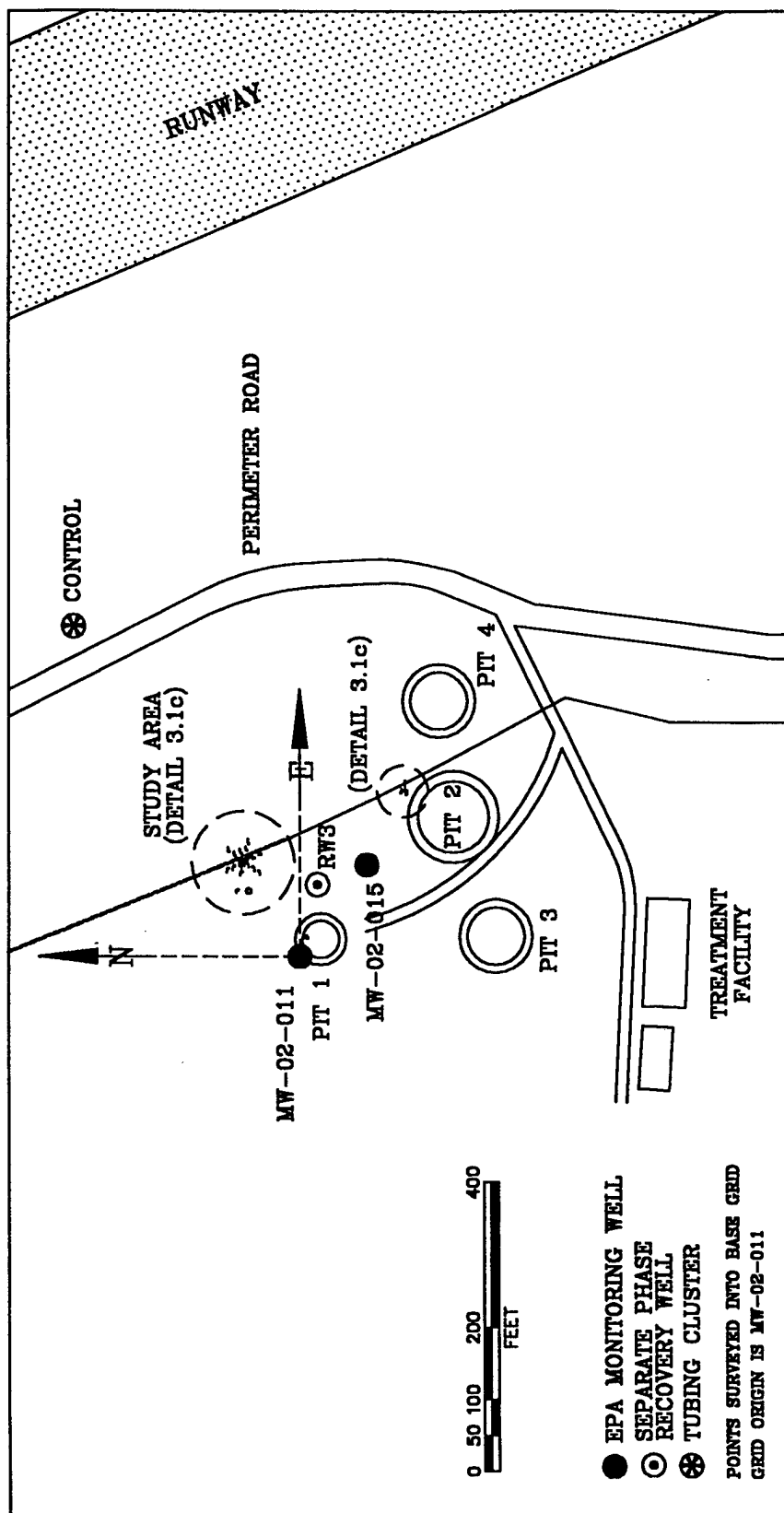


Figure 2.1b Site Plan: Fire Training Area FT-002

TABLE 2.1 SOIL GAS DATA MAY 1994 [PARSONS ENGINEERING SCIENCE (1995)]

| Designatio | Depth, ft | p _X , % | p _C , % | P _{METHANE} , % | p _G , ppm | p _Y ^b |
|------------|-----------|--------------------|--------------------|--------------------------|----------------------|-----------------------------|
| 12PTR1N | 7.0 | 18.8 | 1.1 | <0.1 | 320 | 0 |
| 12PTR1N | 16.0 | 17.3 | 1.8 | <0.1 | 180 | 0 |
| 12PTR1N | 25.0 | 13.7 | 3.3 | <0.1 | 260 | 0 |
| 12PTR1N | 34.0 | 0.0 | 10.4 | 0.6 | 1000 | 3 |
| 14PTR2S | 7.0 | 2.5 | 8.7 | 22.1 | 4700 | 5 |
| 14PTR2S | 16.0 | 0.0 | 11.0 | 24.2 | >4000 | 6 |
| 14PTR2S | 25.0 | 0.0 | 11.3 | 38.7 | * | 7 |
| 14PTR2S | 34.0 | 0.0 | 11.4 | 63.0 | * | 5 |
| 30PTR3S | 7.0 | 13.0 | 4.9 | <0.1 | 490 | 0 |
| 30PTR3S | 16.0 | 8.6 | 7.3 | <0.1 | 360 | 0 |
| 30PTR3S | 25.0 | 4.9 | 8.6 | <0.1 | 320 | 0 |
| 30PTR3S | 34.0 | 0.0 | 11.2 | <0.1 | 850 | 0 |
| 40PTR2N | 7.0 | 15.8 | 3.4 | <0.1 | 100 | 0 |
| 40PTR2N | 16.0 | 12.5 | 5.3 | <0.1 | 150 | 0 |
| 40PTR2N | 25.0 | 1.8 | 10.4 | 4.1 | 2000 | 0 |
| 40PTR2N | 34.0 | 0.0 | 11.3 | 66.3 | 6000 | 3 |
| 44PTR2N | 7.0 | 18.0 | 1.0 | <0.1 | 290 | 0 |
| 44PTR2N | 16.0 | 14.5 | 2.7 | <0.1 | 285 | 0 |
| 44PTR2N | 25.0 | 7.3 | 6.3 | <0.1 | 320 | 0/+1 |
| 44PTR2N | 34.0 | 4.6 | 7.8 | <0.1 | 330 | 3 |
| 48PTR4N | 7.0 | 17.7 | 1.3 | <0.1 | 270 | 0 |
| 48PTR4N | 16.0 | 16.5 | 2.1 | <0.1 | 300 | 0 |
| 48PTR4N | 25.0 | 2.1 | 8.7 | <0.1 | 750 | 0 |
| 48PTR4N | 34.0 | 0.0 | 10.2 | 28.7 | 3000 | 3 |

^aby volume as hexane.

^brelative sniffer measure.

has been contaminated due to vertical and lateral migration of the chemicals that escaped being burned. During training exercises, the pits were typically saturated with water before the addition of from 75-100 gallons of fuel. Prior to the 1980's, a maximum of 2,000 gallons of fuel was dumped into the pits and ignited weekly [Radian (1985)].

Numerous site investigations have been conducted in order to characterize site FT-002 [Parsons ES (1995)]. Radian (1985) conducted a preliminary site assessment. E.C. Jordan Co. (1989a, 1990, 1989b, 1991a, 1991b) conducted a site inspection, a Phase I remedial

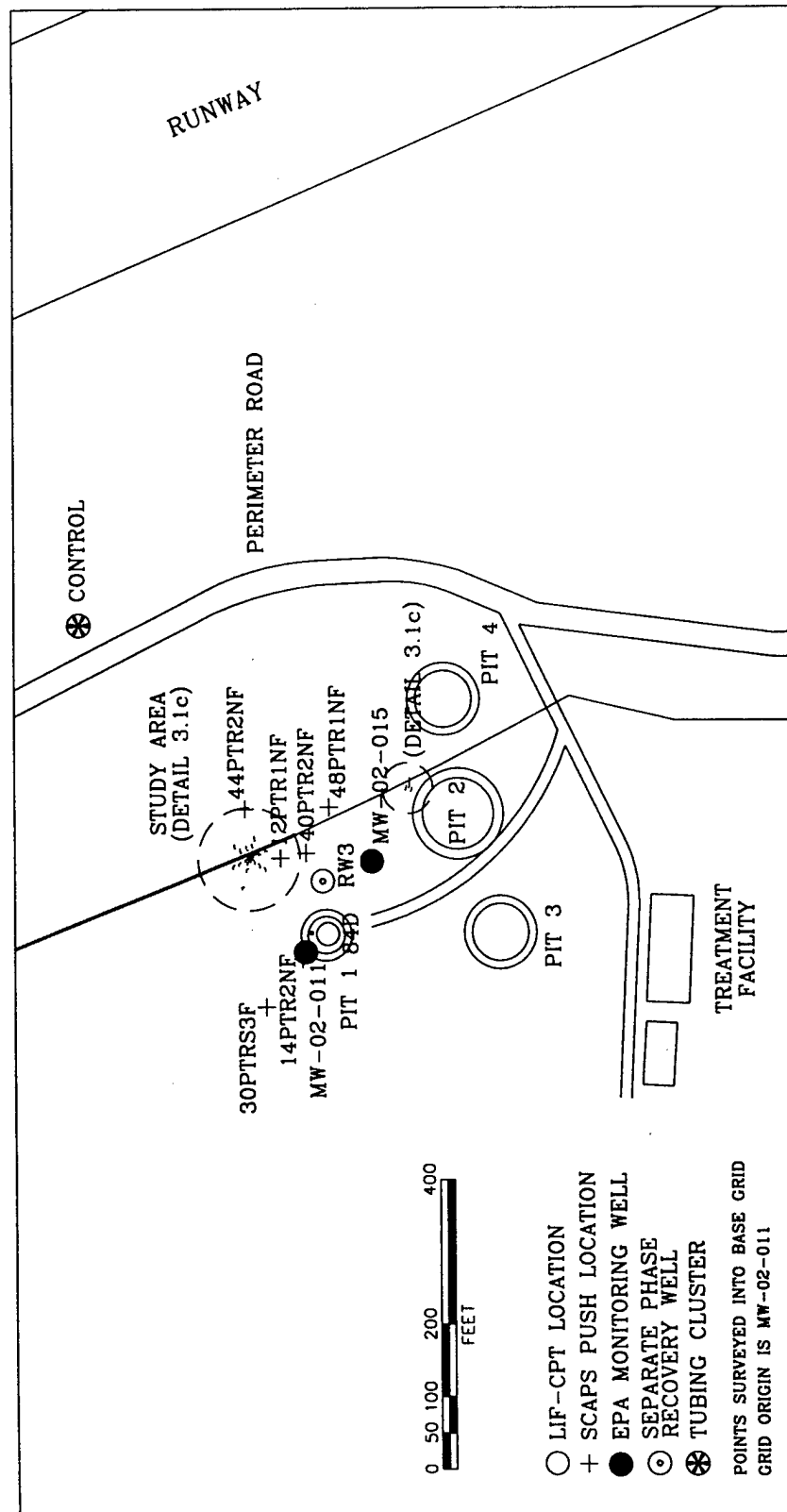


Figure 2.2 Soil Gas Sampling Locations [Parsons Engineering Science (1995)]

investigation, two free product recovery pilot tests, and a drainage flow study. ABB Environmental, Inc (1992) conducted a soil remediation investigation and, together with URS Consultants, Inc. (1993) a Phase II ground water remedial investigation.. In addition, URS Consultants, Inc. (1993) completed a Phase II feasibility study report for the site. The Parsons (1995) data were collected in part by researchers from the United States Environmental Protection Agency (USEPA) Robert S. Kerr Environmental Research Laboratory (RSKERL). This data was combined with that collected under the Installation Restoration Program to determine if natural attenuation mechanisms would eliminate ground water as a pathway for exposure. The site is on the National Priorities List (NPL) under the USEPA's Superfund program. In addition, site FT-002 was selected as a field scale bioventing test site under the Air Force Center for Environmental Excellence (AFCEE) Bioventing Test Initiative.

Previous investigations at the site have included: soil gas surveys, a magnetometer survey, ground penetrating radar, seismic refraction, terrain conductivity, laboratory clay testing, grain size analysis, standard hollow stem auger soil sampling, and a cone penetrometer survey. As part of the latest Parsons-ES effort [Parsons ES (1995)], several investigative techniques were used to further characterize the site. Soil profiling was conducted at the site using tip resistance, friction ratio, pore pressure values, and Laser Induced Fluorescence (LIF) in an instrumented Cone Penetrometer Testing tool and 5-foot and 2-foot Mostep soil samplers. Soil gas data were collected during the penetrometer pushes. Ground water samples were collected at the site using a cone penetrometer tool with a modified discrete sampler, a Geoprobe water sampler, monitoring wells installed in boreholes, and a HydroPunch sampler. Several aquifer tests were conducted including pump, slug, and rising head tests.

A dual pump LNAPL recovery system was installed at the site in 1993 consisting of four recovery wells, a ground water treatment building, and a product storage building. While initial recoveries were good (30-65 gallons product/day), recovery rates since have dramatically dropped. In 1993 and 1994, bioventing wells and associated vapor monitoring points were installed near each of the four fire training pits [Engineering Science (1993a)]. Initial tests conducted indicated that oxygen depleted conditions existed at the site and that the addition of oxygen would most likely stimulate aerobic biological fuel degradation. An extended, 1 year bioventing test was conducted at Pit 3 with encouraging results. However, at the time of the Parsons Engineering Science (1995) report, the New York State Department of Environmental Conservation (NYSDEC) had not approved the bioventing plan for the other three pits.

Parsons Engineering Science (1995) conducted a limited air sparging test at site FT-002 in May 1994 to assess the feasibility of using sparging technology to remove chlorinated solvents from the ground water. A sparge point was installed along with five ground water monitoring points radially located between 3 and 20 feet away from the sparge point. Air was injected at 15 PSI with a flow rate of 80 SCFH for 6 days. Water samples were collected every other day and were analyzed for TCE, cis-DCE, trans-DCE, and vinyl chloride. Contaminant levels at all sampling points decreased by an average of 15% by the end of the test. Points containing ground water with the highest contaminant concentrations experienced the greatest decrease in concentration as a result of the sparge test.

**TABLE 2.2 SOLID CORE ANALYSIS FROM BOREHOLE 84D DECEMBER 1993
[PARSONS ENGINEERING SCIENCE (1995)]**

| Depth, ft | T, mg/kg ^a | T _{TCE} , mg/kg ^b | Depth, ft | T, mg/kg | T _{TCE} , mg/kg |
|-----------|-----------------------|---------------------------------------|-----------|----------|--------------------------|
| 3-3.5 | BLQ ^c | NS ^d | 17-17.5 | 5400 | ND ^e |
| 3.5-4 | BLQ | NS | 17.5-18 | 4480 | BLQ |
| 4-4.5 | BLQ | NS | 18-18.5 | 4230 | BLQ |
| 4.5-5 | BLQ | NS | 18.5-19 | 3450 | BLQ |
| 5-5.5 | BLQ | NS | 19-19.5 | 3030 | BLQ |
| 5.5-6 | BLQ | NS | 19.5-20 | 2880 | BLQ |
| 6-6.5 | 176 | NS | 20-20.5 | 2360 | BLQ |
| 7-7.5 | BLQ | NS | 20.5-21 | 1150 | ND |
| 7.5-8 | BLQ | NS | 21-21.5 | 1790 | BLQ |
| 8-8.5 | BLQ | NS | 21.5-22 | 2340 | BLQ |
| 8.5-9 | BLQ | NS | 22-22.5 | 2220 | BLQ |
| 9-9.5 | BLQ | NS | 22.5-23 | 3240 | BLQ |
| 9.5-10 | BLQ | NS | 23.5-24 | 194 | ND |
| 10-10.5 | BLQ | NS | 35-35.5 | 112 | BLQ |
| 10.5-11 | BLQ | NS | 35.5-36 | 99 | ND |
| 11-11.5 | BLQ | NS | 36-36.5 | 3380 | 5.06 |
| 11.5-12 | BLQ | NS | 36.5-37 | 4780 | 17.4 |
| 12-12.5 | BLQ | NS | 37-37.5 | 7570 | 57.2 |
| 12.5-13 | BLQ | NS | 37.5-38 | 10100 | 169 |
| 13-13.5 | BLQ | NS | 38-38.5 | 18800 | 210 |
| 13.5-14 | BLQ | NS | 38.5-39 | 39400 | 615 |
| 14-14.5 | BLQ | ND | 39-39.5 | 75300 | 931 |
| 14.5-15 | BLQ | ND | 39.5-40 | 125000 | 1280 |
| 15-15.5 | 94 | ND | 40-40.5 | 120000 | 1130 |
| 15.5-16 | 4120 | BLQ | 40.5-41 | 78700 | 876 |
| 16-16.5 | 2080 | BLQ | 41-41.5 | 19400 | 314 |
| 16.5-17 | 5180 | BLQ | 44-44.3 | BLQ | ND |

^aTotal petroleum hydrocarbon mass/mass dry soil.

^bTrichloroethylene mass/mass dry soil.

^cBelow quantitation limit.

^dNot sampled.

^eNot detected.

Parsons Engineering Science (1995) report a wealth data describing the composition of contaminated soil gas, soil, and separate phase petroleum LNAPL from numerous sampling points. Data relevant to the UMASS study are included here. Figure 2.2 displays the location of the Parsons Engineering Science (1995) sampling points. We modify the reported coordinates to reflect a datum at monitoring well MW-02-011, and list them in Table 2.3.

**TABLE 2.3 BASE GRID AND MEAN SEA LEVEL COORDINATES OF BASE
ENGINEERING SAMPLING POINTS**

| Designation | Data | North, ft | East, ft | Elevation, ft^a |
|--------------------|-----------------------|------------------|-----------------|----------------------------------|
| MW-02-011 | Grid origin | 0.00 | 0.00 | 260.35 |
| RW3 | Separate phase sample | 97.93 | -23.88 | 255.58 |
| 84D | LNAPL profile | 24.90 | -30.86 | 260.00 |
| 12PTR1N | Soil gas profile | 129.14 | 35.07 | 255.90 |
| 14PTR2N | Soil gas profile | -9.67 | 4.19 | 260.00 |
| 30PTRS3 | Soil gas profile | -75.87 | 55.51 | 262.50 |
| 40PTR2N | Soil gas profile | 136.30 | -0.70 | 255.74 |
| 44PTR1N | Soil gas profile | 197.14 | 84.12 | 254.50 |
| 48PTR1N | Soil gas profile | 199.19 | -32.88 | 253.50 |

^aElevation is estimated.

2.1.2 Soil Gas and LNAPL Composition

Parsons Engineering Science (1995) used a Geoprobe cone penetrometer to collect soil gas samples from 24 depths in six boreholes adjacent to the site area (12PTR1N, 14PTR2S, 30PTR3S, 40PTR2N, 44PTR2N, and 48PTR4N). The boreholes are sketched in Figure 2.2, with coordinates included in Table 2.3, referred to monitoring well MW-02-011 as the grid datum. Oxygen p_X , total hydrocarbon p_G , and carbon dioxide p_C partial pressures were measured with portable hydrocarbon meters, along with methane p_{METHANE} and trichloroethylene p_Y levels. Elevated total hydrocarbon and carbon dioxide concentrations were found throughout the fire training area, with highest values near the capillary fringe. The soil gas is oxygenated, though at decreasing levels near the fringe, in all boreholes except 14PTR2. This latter profile lies in Pit 1, which experienced contaminated liquid infiltration during fire training operations. Trichloroethylene vapors were detected near the capillary fringe in 12PTR1, 40PTR2, 44PTR2, and 48PTR4. Trichloroethylene was not sensed in 30PTR3, but was found at all depths in the Pit 1 borehole.

Parsons Engineering Science (1995) present a vertical profile of solid core analyses as well, which we cite in Table 2.2. The soil was sampled continuously from borehole 84D, whose location is shown in Figure 2.2 and coordinates are listed in Table 2.3. The borehole is positioned inside Pit 1. Separate phase petroleum was found over an interval from 4.7 to 12.6 m below the ground surface, with a maximum reported total hydrocarbon contamination T_{MAX} of 125,000 mg/kg. Separate phase trichloroethylene was found over the 11.0 to 12.6 m interval, with a maximum reported T_{TCEMAX} value of 1,130 mg/kg. The ratio of TCE to total petroleum hydrocarbons in the separate phase ranged from 0.0015 to 0.0156 with an average of 0.0105. Parsons Engineering Science (1995) report LNAPL compounds in a free product sample bailed from recovery well MW-02-015 in December 1993. Table 2.4 lists the results of a semiquantitative gas chromatograph/mass spectrometer analysis of the LNAPL.

**TABLE 2.4 SEMIQUANTITATIVE GC/MS ESTIMATE OF LNAPL COMPOSITION
DECEMBER 1993 FREE PRODUCT SAMPLE FROM MW-002-011
[PARSONS ENGINEERING SCIENCE (1995)]**

| Compound | Conc., ppm | Mass, % | Compound | Conc., ppm | Mass, % |
|------------------------|---------------|---------|-------------------|---------------|---------|
| Benzene | 1,400 | 0.83 | Dodecane | 11,100 | 6.59 |
| Toluene | 8,970 | 5.32 | Heptane | 1,170 | 0.70 |
| Ethylbenzene | 5,440 | 3.23 | Hexane | 4,090 | 2.43 |
| m Xylene | 13,700 | 8.13 | Napthalene | 1,370 | 0.81 |
| o Xylene | 4,570 | 2.71 | Nonane | 15,300 | 9.10 |
| p Xylene | 4,920 | 2.92 | Octane | 14,600 | 8.67 |
| 1,2,3 trimethylbenzene | 3,560 | 2.11 | Pentadecane | 2,980 | 1.77 |
| 1,2,4 trimethylbenzene | 6,960 | 4.13 | Tetradecane | 5,490 | 3.26 |
| 1,3,5 trimethylbenzene | 4,110 | 2.44 | Trichloroethylene | 16,400 | 9.74 |
| 1 methylnapthalene | 1,400 | 0.83 | Tridecane | 9,320 | 5.53 |
| 2 methylnapthalene | 1,990 | 1.18 | Undecane | 12,000 | 7.12 |
| Decane | 17,600 | 10.5 | | | |

Trichloroethylene is reported as 9.10% by mass of the measured concentrations, which is an order of magnitude higher than the reported T_{TCE}/T ratios found in the solid core analyses of Table 2.2.

2.2 Assimilative Capacity of the Vadose Zone

2.2.1 Hydrocarbon Vapor Degradation

The assimilative capacity of the vadose zone may be attributed to microorganisms residing in residual soil moisture. These aerobic organisms create carbon dioxide and consume hydrocarbon vapors and oxygen, so that soil gas sampling is commonly used to assess the natural attenuation potential of the vadose zone [AFCEE (1994)]. The ability of the vadose zone microbes to degrade petroleum hydrocarbon vapors is well documented in the field and laboratory. Kampbell et al. (1987) measure the ex situ treatment efficiency of a biofilter to degrade propane vapors, while Ostendorf and Kampbell (1991) present an account of natural diffusive attenuation of aviation gasoline vapors in the unsaturated zone. Bioventing [AAEE (1994)] and air sparging [Hinchee (1994)] are treatment alternatives that exploit the assimilative capacity of the vadose zone for volatile hydrocarbons. We discuss these remedial measures in more detail in subsequent Sections.

2.2.2 Trichloroethylene Degradation

Bourg et al. (1992) present a list of the most common chlorinated contaminants found in the subsurface in order of likely occurrence:

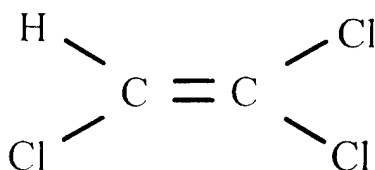


Figure 2.3 Trichloroethylene Molecule

- Trichloroethylene
- Tetrachloroethylene
- 1,1,1-Trichloroethane
- Dichloroethene
- Dichloroethane
- Carbon Tetrachloride
- Vinyl chloride
- Dichloromethane

The list suggests that trichloroethylene is the most common chlorinated hydrocarbon compound likely to be found in the subsurface. Trichloroethylene is a colorless, volatile, chlorinated compound containing two carbon atoms, three chlorine atoms and one hydrogen atom (Figure 2.3). The following are some properties of TCE

- | | |
|----------------------|---------------------------|
| • Molecular Weight | 131.4 g/mol, |
| • Specific Gravity | 1.46 |
| • Solubility | 1100 mg/L, |
| • Vapor Pressure | 58 mm Hg @ 20°C. |
| • Henry's Law Const. | 0.39 dimensionless @ 25°C |

Contrary to most chlorinated compounds, hydrocarbon compounds are in a reduced state and energy can be gained through chemical oxidation. Thus, hydrocarbon compounds such as gasoline, other fuel oils, and their distillates are particularly amenable to aerobic biodegradation [Ostendorf and Kampbell (1991), Hickey (1995a), Kerfoot (1990)]. On the other hand, halogenated compounds are already in an oxidized state and reduction is the energetically favored process. While many studies have focused on the biodegradation of hydrocarbon compounds, only recently has there been a focus on the biodegradation of chlorinated compounds. There is still a great deal to be learned regarding the biological processes that occur with various chlorinated compounds in the subsurface environment but there are several processes that are generally accepted as occurring. Table 2.5 lists these mechanisms.

Many TCE degradation mechanisms are anaerobic. A number of studies [Vogel and McCarty (1985), Freedman and Gosset (1989)] have shown that tetrachloroethylene (PCE) can be transformed to TCE, dichloroethylene (DCE), vinyl chloride (VC), and partially to ethylene

**TABLE 2.5 MECHANISMS FOR BIODEGRADATION OF SELECTED
CHLORINATED COMPOUNDS**

| Oxygen | Substrate | Carbon Tetrachloride | Tetrachloro- ethylene | Trichloro- ethylene | Trichloro- ethane |
|-----------|--------------|-------------------------|--------------------------|------------------------|----------------------|
| Aerobic | Primary | no | no | no | no |
| Aerobic | Cometabolite | no | no | yes | maybe |
| Anaerobic | Primary | no | maybe | maybe | no |
| Anaerobic | Cometablite | yes | yes | yes | yes |

(ETH) under methanogenic conditions by the process of reductive dehalogenation. The addition of an electron donor (methanol) is required to sustain the process with the rate limiting step being the transformation of VC to ETH. Pavlostathis and Zhuang (1991) demonstrate the reductive dechlorination of TCE by sulfate reducing bacteria, via the pathway shown in Figure 2.4.

While anaerobic degradation of TCE has been well researched, direct aerobic metabolism has yet to be documented. Thus far, the only cases of aerobic metabolism of TCE have been through cometabolism. Cometabolism is the biological transformation of a compound by a system of enzymes only while in the presence of, or immediately after it is exposed to, a cosubstrate. A cosubstrate is a compound which allows a system of enzymes to transform a compound that is not transformed in the absence of a cosubstrate. A cosubstrate can be an enzyme or an electron donor. Cometabolic degradation of TCE by methanotrophic bacteria has been well documented in batch and column studies [Lanzarone and McCarty (1990), Speitel and Closmann (1991), Wilson and Wilson (1985), Alvarez-Cohen et al. (1992)] and saturated zone field experiments [Semprini et al. (1991)]. Under natural conditions without contamination, indigenous, methanotrophic bacteria utilize methane as an electron donor and oxidize it to ethanol. This is accomplished using the bacterially produced enzyme, methane monooxygenase (MMO) as a catalyst. Due to a lack of substrate specificity, the MMO enzyme will attack the TCE molecule as well. During the process of TCE utilization, the MMO enzyme inserts an oxygen atom across the double bond of the TCE molecule forming an epoxide. The epoxide is then mineralized through hydrolysis to CO₂ and H₂O (Figure 2.4). While MMO will degrade TCE as it will methane, no energy is gained from the reaction. For the organisms to flourish, they require methane, and will degrade TCE as an aside. This cometabolic phenomenon can be exploited to treat TCE contamination in-situ. Several previous studies have shown that the addition of methane and oxygen into the subsurface can stimulate the growth of organisms that produce MMO [Lanzarone and McCarty (1990), Alvarez-Cohen et al. (1992), Speitel and Closmann (1991)]. While methane is typically the substrate that allows for the production of MMO, it has also been shown that MMO producing organisms can be grown with methanol as a substrate [Fitch et al. (1996)]. When attempting to stimulate the cometabolism of TCE through use of MMO, one must design a system to properly balance the available methane or other substrate to the organism population. If an oversupply of methane is provided, the organisms will choose to degrade methane only and not degrade TCE. This is competitive inhibition and it has been shown to occur in aquifers between methane and TCE [Semprini et al. (1991)]. On the other hand, without enough methane, because the organisms gain no energy from TCE

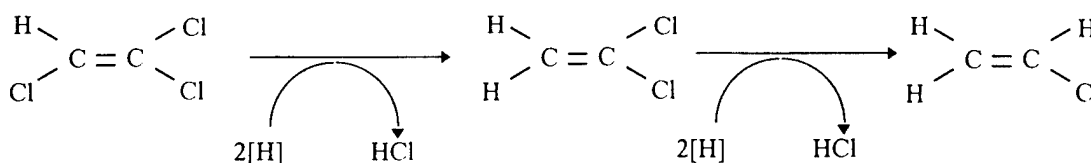


Figure 2.4 Anaerobic Dehalogenation of Trichloroethylene

degradation, the bacteria population will not thrive, therefore a careful balance must be achieved between methane and TCE concentrations. Wilson and Wilson (1984) show through column studies that TCE can be degraded cometabolically using a mixture of natural gas and air. The natural gas consisted of 77% methane, 10% ethane, 7% propane, 2.4% *n*-butane, 1% *iso*-butane, 1.5% pentanes, and 0.7% hexanes. Using radiolabeled TCE, the authors determine that, in columns exposed to the gas/air mixture, 99% of the radiolabeled carbon was recovered as CO₂. Wilcox et al. (1995) also induce biodegradation of TCE using propane.

Lanzarone and McCarty (1990) study the methanotrophic degradation of TCE and 1,2-DCA in column experiments. Radiolabeled TCE and 1,2-DCA were introduced into columns filled with saturated sandy aquifer materials. Dissolved propane and methane was tested at several concentrations. It was found that no TCE degradation occurred with propane and when methane was added at levels of 4.5 mg/L and above. An optimal dissolved methane concentration of 1.5 mg/L led to TCE degradation. Alternating high and low methane levels also led to TCE metabolism. The addition of nutrients did not have any noticeable effect on degradation rates. Speitel and Cloosmann (1991) studied degradation rates of TCE, 1,2-DCE and chloroform in unsaturated soil batch experiments. The authors exposed soil to a methane/air atmosphere. Results showed that 1,2-DCE degraded fastest followed by TCE and then chloroform. Degradation rates were based only on removal of the parent compound.

In addition to methane utilizing bacteria, it has also been demonstrated that bacteria capable of aerobically degrading certain aromatic hydrocarbon compounds such as toluene [Fan and Scow (1993), Landa et al. (1994), Malachowsky et al. (1994), Mars et al. (1996), Leahy et al. (1996)] and phenol [Hopkins et al. (1993), Hecht et al. (1995)] can cometabolically degrade trichloroethylene. The enzyme toluene dioxygenase (TDO) has been strongly implicated in the cometabolic degradation of TCE in the presence of toluene [Nelson et al. (1988), Li and Wackett (1992)] as well as toluene monooxygenase [Luu et al. (1995)]. Fan and Scow (1993) studied cometabolism of TCE with toluene in unsaturated soils by indigenous microorganisms. Experiments studying the effects of TCE and toluene concentrations on TCE and toluene degrading bacteria populations were carried out by Mu and Scow (1994). Degradation of TCE by a hybrid ring dioxygenase is presented by Furukawa et al. (1994).

There are additional factors required for metabolism whether aerobic or anaerobic. A nitrogen source is one of the primary nutrients required for biological growth. However, the addition of nitrogen is not usually required. Previous work has indicated that methane oxidizing

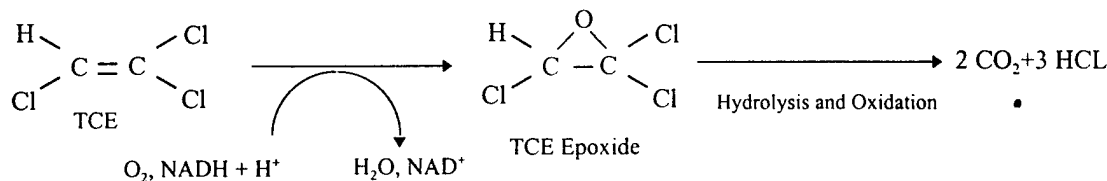


Figure 2.5 Cometabolism of Trichloroethylene

bacteria, when supplied with molecular nitrogen, are able to oxidize TCE as efficiently as cells supplied with ammonia (NH_4^+) and nitrate (NO_3^-) [Chu et al. (1995)]. In addition, Lanzarone and McCarty, 1990 found that the addition of nitrogen and phosphorous compounds in aerobic column studies did not conclusively effect degradation rates. Enzein et al. (1994) present a study in which a methanotrophic fluidized bed is used to create a combination aerobic and anaerobic environment. While TCE can be degraded anaerobically and aerobically, PCE can not and requires anaerobic conditions. Under strictly anaerobic conditions, VC and DCE tend to build up as by-products of TCE degradation. This combination aerobic/anaerobic environment allowed for the degradation of PCE and its daughter products (TCE, DCE, and VC).

Recent studies indicate that the root zone and rhizosphere offer increased potential for microbial degradation of toxic compounds. The root zone is the upper area of the soil containing the roots of the plants growing at the surface. The rhizosphere is the interface where plant roots come into contact with the surrounding soil. There are two schools of thought regarding possible mechanisms for the enhanced degradation ability of the root zone/rhizosphere [Anderson and Walton (1995)]. The first is that plant roots release compounds that aid in overall microbial growth allowing for an increased microbial population density. The second is that the plant roots exude compounds that are analogs to anthropogenic contaminants. Thus, organisms are present and acclimated which are capable of degrading contaminants. A study utilizing radiolabeled TCE along with vegetated and non vegetated soil from a TCE contaminated site yielded promising results. Vegetated soils with both acclimated and non acclimated plant species showed a marked increase in their ability to transform TCE to CO_2 . There was additional uptake of [^{14}C] in plant tissues which appeared to be specific to plant species and water uptake rate [Anderson and Walton (1995)]. Boyle and Shan (1995) conducted laboratory studies on the biodegradation capacity of rhizosphere and non rhizosphere soils with four compounds: phenol, 2,4-Dichlorophenol (2,4-DCP), 2,4-Dichlorophenoxyacetic acid (2,4-D), and 2,4,5-Trichlorophenoxyacetic acid (2,4,5-T). Results showed that rhizosphere soils played a key role in the mineralization of the more recalcitrant compounds (2,4-D and 2,4,5-T) but little or no difference was seen in degradation rates between the two types of soils for phenol and 2,4-DCP.

2.3 Soil Vapor Remediation Alternatives

There are many remediation schemes for treating contamination in the subsurface. The most common can be grouped into three categories: ground water pump and treat, soil

excavation, and soil venting/vapor extraction systems, the category in which bioventing is placed. Early attempts to remediate sites with hydrocarbon contamination involved ground water pump and treat technology. Ground water was extracted from the subsurface through a network of recovery wells or trenches, treated, and then reinjected, land applied, or sent to a water treatment facility. As more advanced attempts to treat ground water evolved, dual pump or skimmer pump recovery systems were used. In these systems, one pump operated as a ground water depression pump and a second pump or passive element acted to remove any floating separate phase product that accumulated on the water surface as a result of the ground water depression.

Because the residual phase can serve as a constant source of contamination, it becomes all but impossible, despite great magnitudes of ground water being pumped to the surface, to remediate a site to low levels of contaminant concentration. Ground water samples collected within a recovery well appear to be clean but, in fact, if the flow is stopped and the ground water is allowed to come to equilibrium with the surrounding contaminated soils, contaminant levels will rise again to near initial levels. What must be addressed are the residual trapped hydrocarbon compounds that are serving as the source. Pump and treat strategies are effective at removing the bulk, mobile separate phase from the subsurface and also a portion of the contaminated ground water. However, pump and treat technologies generally are not sufficient to remove the majority of a typical subsurface hydrocarbon spill. A large portion of the spill typically remains in an immobile, discontinuous phase within the soil pores both above and below the water table. The immobile NAPL phase serves as a continuous hydrocarbon source to the surrounding ground water.

2.3.1 Soil Vapor Extraction

Several different strategies are typically implemented to address the residual phase,. Soil vapor extraction (SVE) or in situ air stripping is one strategy that is in wide use. The principles of this technique are as follows. A vent well is installed so that it is screened through or near the interval of soil contamination. A blower is connected at the surface to the end of the well and a vacuum is induced on the well. Soil gas, including gaseous contaminants, is pulled to the surface where it is generally treated before being released to the atmosphere. When the gas is withdrawn from the subsurface, a pressure void exists in the vadose zone such that atmospheric air from the surface is drawn down to replace it. This constant flow of air strips volatile contaminants from the subsurface and brings them to the surface where the air stream can be treated.

To be amenable to SVE, a site must contain substances that are volatile enough to be stripped by this technique. Substances must partition from the separate phase or dissolved phase into the gaseous phase at a rate that makes treatment by this method possible in a reasonable amount of time. High vapor pressure and low solubility are desired characteristics (Rathfelder et al., 1995). Secondly, the site soils must be permeable enough to allow the SVE system to move air through the area of contamination. While SVE is an effective, proven technique for the in situ treatment of contaminated vadose zone soils, it does have several drawbacks. Spills of fuel oils such as diesel and heating oil contain fractions of heavier, less volatile compounds. Constituents such as naphthalene, phenanthrene, and other PAHs have relatively low vapor

pressure constants and therefore volatilize very slowly. The slow volatilization means that the process is severely rate limited with respect to these compounds. These heavier compounds therefore, can not be effectively treated by SVE. Another drawback to SVE is that the compounds that are stripped from the subsurface and brought to the surface often must be treated to meet regulatory emissions levels. Often the cost of treating the off gas exceeds that of construction and operation of the SVE system.

Whether planned or not, during the SVE process more than just air stripping of volatile compounds occurs. When soil gas is withdrawn from the subsurface, air from the atmosphere flows in to replace it. The points where air enters the ground vary based on withdrawal rate and site geology, but at some point the withdrawn gas volume is replaced. Atmospheric air contains 20.9% oxygen by volume. Generally, in an area of high hydrocarbon contamination, soil gas oxygen levels are greatly depleted when compared to atmospheric oxygen levels.

At most hydrocarbon spill sites there are bacteria present in the subsurface that are capable of degrading many of the hydrocarbon compounds that exist there. The most efficient of these bacteria are aerobic due to the fact that using O_2 as an electron acceptor yields more energy for the bacteria than alternative acceptors such as nitrate, sulfate, or iron. In order to function, the bacteria require four things: an electron donor, electron acceptor, a carbon source, and water. In addition, several trace nutrients are required. The hydrocarbon compounds provide the electron donor and the carbon source. Assuming adequate moisture is present along with necessary micronutrients, the requirement that is lacking is typically oxygen. Thus the bacteria are hindered from further growth by a lack of O_2 . By increasing the levels of O_2 in the subsurface, a corresponding increase in bioactivity and resultant depletion of hydrocarbon compounds by mineralization will occur. SVE, by pulling oxygen rich gas from the subsurface, inadvertently stimulates biological growth. The results of increased biological activity have been seen at SVE sites [Gomes-Lahoz et al. (1994)]. Bioventing exploits this aspect of soil vapor extraction.

2.3.2 In Situ Bioventing

The technique of in situ bioventing has become an accepted practice for remediating soils contaminated with hydrocarbon compounds. Bioventing is an effort to enhance the indigenous microbial population's hydrocarbon degrading capability by supplying electron acceptor, usually in the form of atmospheric O_2 . In many ways, a bioventing system operates with the same basic equipment and under the same principles as SVE. A bioventing system maximizes microbial degradation of contaminant compounds while minimizing withdrawal of contaminants to the ground surface where they would require additional treatment. Advantages of bioventing over SVE and other methods include the fact that heavy compounds such as diesel and heavy heating oils can be effectively treated in-situ [Downey et al. (1995), Leeson et al. (1993), Bulman et al. (1993), Dupont (1993), Long (1992)]. These heavy compounds can not otherwise be brought to the surface economically for treatment.

In order for bioventing to work successfully, sufficient water must be present to permit the transfer of enzymes necessary for biodegradation. Nutrients such as orthophosphate and

ammonium nitrogen are sometimes added at the surface along with moisture addition to optimize biodegradation [Long (1992)].

The following list, adapted from Long (1992), presents parameters that should be known prior to implementation of a bioventing system:

Contaminants

- Compounds Present Above Action Levels for Treatment
- Volatility
- Solubility
- Aerobic Degradability

Site

- Permeability
- Vacuum/ Pressure Requirements
- Air Flow Paths
- Water Table Elevation
- Ability to Lower Water Table

Regulatory

- Permits and Regulations that Apply to Installation of a Bioventing System
- Levels of Government Involved
- Level of Government at which Permits will be Written

Relatively few bioventing field demonstrations have been reported in the literature with most involving JP4 jet fuel, JP5 jet fuel, diesel, and gasoline [Lee and Swindoll (1993)]. The most active bioventing program has been instituted by the United States Air Force. Laboratory treatability studies were conducted at more than a dozen sites. Over half were contaminated with light hydrocarbon compounds such as gasoline, diesel and light to medium weight crude oil. Most sites experienced high removals in the area of 90%. Heavier fuel oil sites experienced less effective treatment. Sites that contained chlorinated solvents such as dichloromethane, tetrachloromethane, chloroform and carbon tetrachloride experienced reductions in these also but this was mostly due to venting with similar effluent concentrations as venting alone. The authors note limited aerobic degradation of these compounds without a cometabolic substrate.

Part of the reason bioventing is effective is that it uses as an electron acceptor. Table 2.6, adapted from Dupont, 1993 presents the number of pounds of carrier required to yield one pound of oxygen for various carrier solutions. It can be seen that 110,000 grams of water saturated with air is required to provide 1 gram of O₂ while the same requirement can be provided with only 4.5 grams of air. As an example, assuming an O₂ requirement of 3gm O₂ per gram of hydrocarbons, a 1,000 gallon fuel spill weighing 7,000 lbs. would require 21,000 lbs. of O₂. If air saturated

TABLE 2.6 COMPARISON OF OXYGEN LEVELS IN VARIOUS CARRIERS

| Carrier Solution | g Carrier/g O ₂ |
|---|----------------------------|
| WATER SATURATED W/AIR | 110,000 |
| WATER SATURATED W/O ₂ | 22,000 |
| H ₂ O ₂ SOLUTION @ 500 mg/l | 2,000 |
| AIR | 4.5 |

H₂O was used, one would need 2,310,000,000 gallons to provide adequate O₂ to remediate the area assuming 100% efficiency. In addition to being a prohibitively large quantity of water to deliver, this much water added to the soil of a relatively small site would greatly reduce soil permeability. While hydrogen peroxide provides more O₂ per gram than oxygen saturated water, initial tests conducted at Eglin AFB, FL using H₂O₂ and nutrients by Hinchee and Ong (1992) showed low reductions of hydrocarbon levels due to poor distribution of H₂O₂ and in addition, a breakdown of H₂O₂. On the other hand, by using air which contains 20.9% O₂ by volume, large quantities of O₂ can be efficiently delivered to the subsurface efficiently without a reduction in permeability. Alternatively, research by Gates and Siegrist (1995) appears to indicate that H₂O₂ is a viable alternative for use where clay soils are contaminated with trichloroethylene.

Bioventing involves supplying oxygen usually in the form of air to the organisms in the subsurface. In the case of a single vent well, air can be withdrawn from an extraction well causing air from the ground surface to be drawn down replacing withdrawn soil gas. In the case of a multiple well installation, inlet wells can be used to allow air to flow directly to deep areas of contamination. As an alternative to withdrawing vapor from the subsurface, air can be forced in under positive pressure. This provides the highest oxygen levels where the air injection well is screened. Bioventing is enhanced by lower air rates and longer flow paths. Bioventing can operate in a vacuum mode, much like SVE, where soil gas is extracted from the subsurface or alternatively, bioventing can be operated in a pressure mode where atmospheric air is forced into the subsurface under positive pressure. In the vacuum configuration, air containing O₂ enters the subsurface from the ground surface ideally over the entire area of influence covered by the collection/extraction well. Air is pulled downward and radially inward towards the collection/extraction well. In the positive pressure mode, O₂ enters the subsurface through the injection well and flows radially outward.

An interesting application of bioventing is the use of passive bioventing [Nilson et al. (1991), Wilson et al. (1989), Zwick et al. (1994), Weeks (1979), Pirkle et al. (1992)]. Passive bioventing involves using changes in barometric pressure to cause either soil gas to flow out of, or ambient air to flow into, the subsurface. Passive bioventing is an applicable technology when the required pressure gradient can be periodically generated and when rapid cleanup times are not a priority.

The advantages and disadvantages of utilizing vacuum or pressure systems for bioventing are as follows. The vacuum, or negative pressure, configuration provides one or more central, concentrated points where soil gas can be collected. This makes collection of gas for treatment, if required, much simpler than if soil gas emanating from a positive pressure system requires capture and collection. In the case of a positive pressure system, collection could take the form of a ground sealing device such as a tarp with a collection device attached. With a negative pressure system, gas is being withdrawn from a contaminated area, where there will almost always be volatile contaminants in the gas stream that will either be difficult to degrade or have not had enough time to degrade while in the subsurface. These contaminants will usually require some sort of off gas treatment prior to release to the atmosphere which can be costly.

In addition, a vacuum withdrawal system poses the disadvantage of possibly producing ground water upwelling in the area of the vent well if it is placed too close to the water table [Johnson (1990b)]. This is particularly unadvantageous because, in most cases, the area to be biovented lies just above the water table. When ground water rises and fills the soil pore spaces, O_2 can not reach the degrader organisms and bioventing becomes impractical. A way to solve this problem is to pump the ground water table down, but this requires the installation of additional ground water withdrawal wells.

A positive pressure system does not produce a concentrated contaminant gas stream. Instead, as a response to blowing additional gas into the subsurface, soil gas will be forced to the ground surface in order to reach a pressure equilibrium. Thus, soil gas will be emanating from the soil surface all around within the area of influence of the injection well or wells. This makes gas collection difficult and is often a reason for implementing the vacuum method. However, if the injection system is operated properly, soil gas that is traveling to the surface will have already undergone biotransformation and contaminants will not be emitted at levels above those which have been determined to be unacceptable by regulatory agencies. If operated in this mode, with proper area monitoring, there are no off gases to treat and the overall system operating costs are less.

Prior to implementing a subsurface remediation scheme, it is often advantageous to use a tracer material in order to better understand the hydraulics or pneumatics of an area that is often difficult if not impossible to characterize by other methods. Effective tracers have the properties of being long lived, non reactive, not degradable, non toxic, while being measurable at useful concentrations. Tracers such as Cl^- have been used to characterize saturated media for some time. The unsaturated zone can be characterized using gaseous compounds such as sulfur hexafluoride [Wilson and Mackay (1993)] or helium. Sulfur hexafluoride (SF_6) is readily available and detectable as it is commonly used in the HVAC industry. Helium is also available and has the advantage of diffusing faster in the subsurface due it relatively small molecular size as compared to SF_6 .

2.3.3 Effects of Environmental Variables

There are several compound related properties that must be taken into account to operate a bioventing system properly, many of which are important to SVE also. Of primary importance

to bioventing and not to SVE is the biodegradability of the compound. If indigenous microorganisms cannot degrade the compound, then supplying additional electron acceptor will not aid in the degradation process. Certain compounds are aerobically directly degradable while others require additional substrate be present for the microorganisms and can only be degraded aerobically through cometabolism. Additional properties include volatility, solubility, the sorption characteristics of a particular compound, and finally toxicity.

The volatility of a compound determines what flow rates will be required, the number and placement of bioventing wells as well as the overall pneumatic design. A more volatile compound may be swept by the air stream to areas with additional moisture, surfaces, and organisms. This will speed the degradation process allowing, for example, a drop of a compound to be spread out and degraded simultaneously over a large surface area as opposed to degradation merely occurring at the droplet surface. While volatility is an extremely positive property with regard to SVE, a compound with a high volatility may make efficient bioventing difficult if the volatile compound is carried to the surface before it can be properly degraded. Less volatile compounds will generally require a more effective oxygen distribution network due to the fact that they will stay in an area as opposed to migrating through the subsurface.

Solubility of a compound must be taken into account. If a compound is highly soluble, it will remain trapped within moisture droplets where conditions are not conducive to aerobic degradation. In addition, mass transport within water is several orders of magnitude slower than in a gas. Compounds can only slowly pass through water to the water/gas interface to be degraded. Transport through a water film can often be the rate limiting step during soil venting of hydrocarbon compounds and TCE [Grathwohl (1993)]. While not typically a concern, because of the requirement for living microorganisms, the contaminant level in the vadose zone must be kept below toxic limits. In addition, there cannot be other compounds present in the soil at levels toxic to the degrader organisms.

There are also several soil and site properties which must be within certain ranges for a bioventing system to be effective. Because bioventing requires a thriving microorganism population, it is essential that conditions be as conducive to growth and degradation as possible. Like all living organisms, degrading bacteria require water, an energy and carbon source, trace nutrients, and favorable environmental conditions. Bioventing has been successfully shown to be effective in soils with moisture contents in the range of from 2 to 25% [Downey et al. (1995)]. Fan and Scow (1993) reported moisture levels below 5% inhibited degradation while levels in the 15-30% range yielded good results. The lower moisture limit is based on the fact that the fact that the organisms need some moisture to function and hence survive. The upper moisture limit is driven by a reduction in soil permeability. If high levels of moisture are present in a soil, air filled porosity is greatly reduced and pathways for air flow are subsequently reduced. Without air flow pathways, O_2 can not reach the microorganism population. Experiments conducted by McCarthy and Johnson (1985) showed that the effective diffusion coefficient of TCE in soil columns wetted from field capacity to saturation changed by three orders of magnitude from $1 \times 10^{-6} \text{ m}^2/\text{s}$ to $1 \times 10^{-9} \text{ m}^2/\text{s}$.

Soil permeability is function of grain size distribution and air filled porosity. The intrinsic permeability and the air filled porosity alone control permeability which is not a function of the type of liquid filling the pore space [Stylianou and DeVantier (1995)]. Site permeability assessments with respect to ground water flow have been conducted for decades. More recently, permeability estimates for soil gas flow have been determined using the same and modified ground water flow equations. Johnson et al. (1990b) developed simple models to predict vapor flow rate, vapor flow path, contaminant distribution, and contaminant composition during soil venting operations

Soil temperature is a critical parameter when assessing the feasibility of implementing bioventing at a site. Temperature affects both the viscosity and density of gases but this is negligible over the temperature ranges common in the subsurface [Johnson et al. (1990a)]. However, although less important for bioventing than SVE, the key parameter of vapor pressure increases by a factor of 3 to 4 for every 10°C rise in temperature [Rathfelder et al. (1995)]. Leeson et al. (1993) present a study on bioventing in cold climates. The focus is a JP4 jet fuel spill site at Eielson AFB, Alaska. A bioventing system was designed to operate in a positive pressure mode. To adequately heat the soil as outdoor temperatures dropped, hot water had to be added. Additional water brought additional moisture which lowered soil permeability and made air flow in the soil more difficult. This translated into a decreased supply of O₂ to the microorganisms and thus a decrease in bioactivity. Thus, a balance had to be maintained between supplying enough O₂ and keeping the site warm enough.

In addition to temperature and moisture levels, trace nutrient concentrations must be adequate to support a thriving population of bacteria. Macro and micro nutrients essential for the production of cell materials must be present in the appropriate ratios. A typical macronutrient C:N:P ratio of 100:10:1 is usually adequate. From the literature, it appears that at most bioventing sites, there is not a shortage of such nutrients. Several studies [Dupont (1993), Downey et al. (1995), Hickey (1995b)] have shown that the addition of nutrients, typically nitrogen and phosphorous, did not increase microbial numbers or bioactivity indicating that, at most sites, nutrients are available in adequate quantities. However, there have been some studies conducted [Bulman et al. (1993)] where these nutrients were apparently limiting because, subsequent to nutrient addition, there was a noted rise in microbial numbers and bioactivity. Chu and Alvarez-Cohen (1996) studied the effects of various nitrogen sources on TCE degradation by methane oxidizing bacteria. Results indicated that nitrogen fixing cells exhibited the highest TCE transformation capacity, thus addition of alternative nitrogen sources was not required. Significant degradation of hydrocarbon compounds has been measured in soils with TKN values less than 20 mg/kg soil and P levels less than 3 mg/kg soil [Bulman et al. (1993)]. In addition, research conducted at Tyndall AFB suggests that there is a recycling of nutrients and that there are nitrogen fixing bacteria present [Downey et al. (1995)]. A survey of the literature by Rathfelder et al. (1995) indicated inconclusive results regarding the need for nutrient addition.

One of the only ways to determine if a site is suitable for bioventing is to conduct field tests. A bioactivity test should be conducted to determine if there is an active microbial degrader population present at the area of contamination. In addition, a permeability test should be conducted to determine if the site's pneumatic parameters will allow air and thus O₂ to be

transported to the organisms. The use of in situ respiration tests has become an accepted method for determination of bioactivity potential [Hinchee and Ong (1992), Leeson et al. (1993), Dupont (1993)]. The typical in situ respiration test requires that the site be prepared with an air injection well and several gas monitoring points installed near the injection well. To conduct the test, initial background levels of O₂ and CO₂ are measured at the various monitoring points. Typically, oxygen is measured by discrete sampling with subsequent analysis [Hinchee and Ong (1992)] but can also be measured using more innovative techniques such as in situ oxygen sensors [Li (1995)]. Air is forced into the subsurface through the injection well in an effort to raise the soil gas O₂ levels to ambient (20.9%) levels. Once this has been achieved, air injection ceases and the monitoring points are periodically measured for O₂ and CO₂ levels. Alternatively, Hickey (1995b) used a vapor extraction system to bring O₂ and CO₂ levels in a contaminated area to levels equivalent to biologically less active areas. If there is a viable aerobic degrader community present, the level of O₂ will decrease and the level of CO₂ will rise as the result of aerobic respiration. The test is typically ends when O₂ levels become depleted to less than 5% by volume. When conducting in situ tests it is imperative that background levels of O₂ and CO₂ be measured to accurately determine utilization and production rates due to hydrocarbon degrader metabolism.

Hinchee and Ong (1992) outline a rapid in situ respiration test for quantifying biodegradation rates for hydrocarbons in soil. The paper describes a test to assess whether bioventing is a viable alternative for remediation of petroleum hydrocarbon contaminated soils. The test involves ventilating the soil and then turning off the vent system while monitoring O₂ and CO₂ levels in the surrounding the ventilation point. The paper focuses on 8 contaminated sites with differing geological and climatic conditions. Most of the sites were contaminated with petroleum products (fuels) with two of the sites contaminated with PAHs. The estimated biodegradation rates based on O₂ utilization were generally more reliable than those based on CO₂ production because CO₂ tends to be converted to carbonate in alkaline soils. In addition, CO₂ might not be a good indicator of microbial activity because not all O₂ utilized is converted to CO₂. Results from the 8 sites indicated that O₂ utilization rates were generally .02-.99 %/hour and biodegradation rates ranged from 0.4 to 19 mg/kg/day.

Leeson et al. (1993) conducted in-situ respiration tests at Eilson AFB in Alaska. Air was introduced into the vadose zone and was subsequently shut off. O₂ and CO₂ were monitored over time at various sampling points. As is typical during aerobic respirometry, O₂ was consumed and CO₂ was produced. Experiments were terminated when O₂ concentrations reached 5% or after about 1 week, whichever came first. A test was conducted in October and yielded good results while an additional test was conducted in January which showed microbial activity was less. Hinchee et al. (1992) present a bioventing study that took place at Hill AFB, Utah. In situ respiration tests confirmed that microbial activity was indeed present, leading to the production of CO₂. Isotope ratios of ¹³C/¹²C in soil gas were measured to confirm that the CO₂ source was indeed microbially generated. However, at the end of the study it was determined that the majority of fuel was removed through the physical process of volatilization while approximately 15 to 25% of the fuel was degraded in situ.

Permeability tests are typically conducted by injecting or withdrawing air from a central well and measuring changes in pressure with time in wells spaced away from the center. Alternatively, a tracer gas can be injected into a central well and tracer gas concentration measurements with time can be obtained. Permeability estimates can then be calculated using the same equations used for soil permeability estimates related to groundwater flow.

2.3.4 Air Sparging

Often, in areas with reasonably shallow water tables, if contamination is present in the unsaturated zone it is also present in the ground water. While bioventing directly treats the unsaturated zone, it only indirectly treats the ground water because no air flow occurs in saturated media. The major process occurring to treat the ground water is equilibrium shifting and partitioning to the gaseous phase. This can be a gradual process with ground water acting as a slow, continuous source. Because of this, the technique of air sparging is often used to more rapidly remove compounds from the ground water into the soil gas [Long (1992)], thus enhancing bioventing.

Air sparging is, in effect, air stripping of the ground water. The process is implemented by installing sparge points below the water table. Sparge points are typically narrow bore wells which are screened over a short interval below the water table. Air is forced in under pressure into the sparge point with the bubbles exiting the screened portion of the well, stripping contaminants from the ground water and releasing them into the vadose zone. An excellent, practical paper on air sparging is presented by Brown (1993). An additional approach that presents more contaminated media to the bioventing system is lowering the water table to increase the treatable unsaturated zone [Long (1992)].

2.4 Soil Gas Models

We review the current mathematical modeling efforts in the area of contaminant fate and transport within the subsurface. Models surveyed included all phases of subsurface contamination; NAPL, dissolved and gaseous. Some of them represent modeling efforts alone while others include laboratory experiments for calibration and/or verification.

Mathematical models can be divided into two groups: analytical models and numerical models. Rathfelder et al. (1995) present an excellent overview of the current status of modeling in the areas of SVE and bioventing. Analytical models [Pantazidou and Sitar (1993), Wood and Ginn (1995), Chrysikopoulos (1995), Shan (1995), Baehr and Baker (1995), Hatfield and Stauffer (1993), Jin et al. (1994), Zaidel and Russo (1994), Dietsch and Smith (1995), Batterman et al. (1995), Gierke et al. (1992)] solve the equations through the application of integration techniques such as integral tables, integration by parts, fourier transforms and other convolution techniques. Analytical models tend to be simpler in nature than numerical models, involving fewer parameters and/or dimensions. Numerical models [Kaluarachchi and Islam (1995), Unger et al. (1995), Van Geel and Sykes (1994), Roberts and Wilson (1993)] are iterative in nature and are almost exclusively solved through the use of a computer. Numerical models are typically

divided into two categories: finite difference and finite element. Numerical models tend to be more complex and due to this complexity, usually require a more detailed data base.

Modeling has been used successfully to predict the transport of NAPL in both saturated [Chrysikopoulos (1995), Hatfield (1993), Unger (1995)] and unsaturated [Pantazidou and Sitar (1993), Sleep and Sykes (1989, 1993), Falta et al. (1993)] porous media. Contaminant vapor generation [Roberts and Wilson (1993)], fate and transport [Ostendorf and Kampbell (1991)] along with the effects of contaminant and media [Batterman et al. (1995)] properties can be predicted. Some models are complex, allowing for the study the reaction of gases such as O₂, CO₂, N₂ along with any number of hydrocarbons [Baehr and Baker (1995)]. Other models focus on one contaminant [Chrysikopoulos (1995)] incorporating gas advection, diffusion, liquid to gas transfer, partitioning and sorption of subsurface movement of organic vapors [Gierke et al. (1992)]. The importance of models incorporating multiphase multicontaminant transport is growing in light of the numerous compounds present at sites and their differing properties [Russell (1995)].

The modeling of technologies such as soil vapor extraction [Baehr et al. (1989), Wilson et al. (1994), Beckett and Huntley (1994)] and bioventing [Mohr and Merz (1995)] allows for ballpark feasibility determinations and the possible elimination of unneeded pilot testing in the event of a negative result. On the other hand, a positive result typically requires pilot tests. Biological activity in the subsurface can also be modeled. Examples include the coupling of biodegradation and transport of contaminant vapors [Ostendorf and Kampbell (1991), Jin (1994)], the prediction of metabolic lag due to acclimation and removal of food source [Wood and Ginn (1995)] and cometabolic biodegradation of halogenated compounds [Alvarez-Cohen and McCarty (1991)]. Efforts to increase the efficiency of existing technologies such as the introduction of heated air for vapor extraction [Kaluarachchi and Islam (1995)] or surfactant addition to aid in pump and treat remediation [Deitsch and Smith (1995)] can be predicted through modeling efforts. Models predict air permeability based on simple field tests [Shan (1995)] and couple vacuum extraction with air sparging for use in predicting DNAPL treatment rates [Unger et al. (1995)].

While general transport models incorporate many properties of both the contaminant and media in their equations, others focus on specific properties such as the impact of soil gas humidity on TCE vapor transport [Batterman et al. (1995)]. Sleep and Sykes (1989, 1993) model TCE concentrations numerically, coupling both the aqueous and vapor phases. Density driven flow of organic compounds in the unsaturated zone has also been modeled [Falta et al. (1989)].

3 METHODS AND MATERIALS

The field data base includes data taken from boreholes, stainless steel tubing clusters, vapor probes, and thermocouple arrays distributed across the study area. Figure 3.1 displays the plan location of the various sample points, which were surveyed into the Plattsburgh Air Force Base grid by UMASS personnel using a Topcon 5 sec Total Station (Northeast Supply Co., East Longmeadow, MA). Table 3.1 lists north, east, and vertical coordinates of the UMASS sampling array, relative to mean sea level and a Base monitoring well (MW-02-011).

3.1 Soil Temperature, Grain Size Distribution, and Moisture Content

3.1.1 Soil Temperature

Soil temperature influences the soil gas diffusivity and the ideal gas law in the soil gas transport model, and affects biodegradation rates as well. We installed thermocouple arrays in boreholes SPK1 on 12 October 1995 and 12AT on 2 December 1995. Figure 3.1 displays the location of the two arrays, which consist of thermocouple leads (Omega Engineering Inc., Stamford, CT) attached to 1.91 cm rigid PVC casing deployed through hollow stem augers. The thermocouples are staggered at 0.3 m intervals to a depth of 3 m in borehole SPK1, then spaced a 1.5 m intervals to a depth of 10.7 m. The 12AT array features 0.6 m spacing to a depth of 3 m, then 1.5 m spacing to the 9.1 m depth. We read the leads with an Omega HH 73K1 handheld digital thermometer on 17 sampling trips from 13 October 1995 to 19 December 1996, generating a data base of 377 observations.

3.1.2 Grain Size Distribution

Particle size distributions and soil moisture content were observed in order to confirm our assumption of a homogenous, well drained unsaturated zone with constant air porosity. Soil samples were obtained from boreholes SPK1, SPK2, and 12AY using the Standard Penetration Test and a two inch OD split spoon sampler in accordance with ASTM (1992a) protocol. The split spoon soil samples were measured for recovery and immediately placed into "zip-lock" plastic bags to retain the natural moisture content. In the laboratory, the bagged samples were weighed and an average weight from ten clean dry bags was subtracted to obtain the moist soil weight. The split spoon samples were analyzed for grain size distribution [ASTM (1992b)]. The soil, after being oven dried for 24 hours, was placed into a mortar and a rubber-covered pestle to break up the aggregations of soil particles. The following nest of U.S. Standard Sieves was used in the analysis:

- US Standard 3/8 inch (9.54 mm)
- US Standard No. 4 (4.76 mm)
- US Standard No. 10 (2.00 mm)
- US Standard No. 20 (0.840 mm)
- US Standard No. 40 (0.420 mm)
- US Standard No. 60 (0.250 mm)
- US Standard No. 80 (0.185 mm)

**TABLE 3.1 BASE GRID AND MEAN SEA LEVEL COORDINATES OF UMASS
SAMPLING POINTS**

| Designation | Data | North, ft | East, ft | Elevation, ft |
|--------------------|--------------------------------|------------------|-----------------|----------------------|
| MW-02-011 | Grid origin | 0.00 | 0.00 | 260.35 |
| RW3 | Separate phase sample | 97.93 | -23.88 | 255.58 |
| 12AA | Tubing cluster | 129.66 | 77.49 | 256.26 |
| 12AB | Tubing cluster | 127.37 | 72.53 | 256.37 |
| 12AC | Tubing cluster | 128.36 | 81.92 | 256.54 |
| 12AD | Tubing cluster | 123.62 | 90.75 | 256.41 |
| 12AE | Tubing cluster | 115.21 | 80.39 | 256.70 |
| 12AF | Tubing cluster | 90.52 | 86.04 | 257.32 |
| 12AG | Tubing cluster | 120.19 | 99.09 | 256.46 |
| 12AH | Tubing cluster | 132.03 | 73.06 | 256.30 |
| 12AI | Tubing cluster | 134.85 | 62.82 | 256.22 |
| 12AJ | Tubing cluster | 139.42 | 53.90 | 255.90 |
| 12AK | Tubing cluster | 122.14 | 65.21 | 256.48 |
| 12AL | Tubing cluster | 116.77 | 57.07 | 256.55 |
| 12AM | Tubing cluster | 125.38 | 78.79 | 256.53 |
| 12AN | Tubing cluster | 221.85 | -147.63 | 250.24 |
| 12AO | Tubing cluster | 154.31 | 70.96 | 255.61 |
| 12AP | Tubing cluster | 141.01 | 81.08 | 256.04 |
| 12AQ | Tubing cluster | 143.27 | 98.24 | 255.47 |
| 12AR | Tubing cluster | 137.47 | 90.07 | 255.60 |
| 12AS | LANPL profile | 133.08 | 69.02 | 256.29 |
| 12AT | Tubing cluster | 223.64 | -139.90 | 250.18 |
| 12AU | Tubing cluster | 122.44 | 76.11 | 256.53 |
| 12AV | Tubing cluster | 129.67 | 70.28 | 256.36 |
| 12AW | Tubing cluster | 126.89 | 85.69 | 256.32 |
| 12AX | Tubing cluster | 230.27 | -153.47 | 249.97 |
| 12AY | Grain size distribution | 145.82 | 58.92 | 255.46 |
| 12AZ | Tubing cluster | 142.74 | 77.64 | 254.18 |
| 12BA | Tubing cluster | 138.43 | 85.83 | 255.86 |
| 12BB | TCE profile | 123.21 | 68.83 | 256.48 |
| 12BC | Vapor probe | 120.71 | 70.03 | 256.45 |
| 12BD | Intact core sleeves | 116.27 | 70.48 | 256.47 |
| 12BE | Vapor probe | 121.66 | 77.75 | 256.52 |
| 12BF | TCE profile | 120.75 | 83.74 | 256.61 |
| 12BG | Intact core sleeves | 117.38 | 78.05 | 256.65 |
| 12BGMC | moisture content determination | 121.67 | 79.40 | 256.53 |
| 12BH | Vapor probe | 138.96 | 84.05 | 255.73 |
| 12BI | TCE profile | 142.03 | 88.13 | 255.55 |
| 12BJ | Vapor probe | 145.28 | 92.01 | 255.35 |
| 12BK | Vapor probe | 116.83 | 65.99 | 256.60 |

**TABLE 3.1 (Continued) BASE GRID AND MEAN SEA LEVEL COORDINATES OF
UMASS SAMPLING POINTS**

| Designation | Data | North, ft | East, ft | Elevation, ft |
|--------------------|----------------------------|------------------|-----------------|----------------------|
| 12BM | Vapor probe | 127.59 | 67.54 | 256.45 |
| 12BN | Vapor probe | 117.40 | 87.79 | 256.57 |
| 12BO | TCE profile | 133.52 | 95.23 | 255.78 |
| NA1 | 50 cm tubing cluster, west | 109.95 | 61.89 | 256.63 |
| NA2 | 25 cm tubing cluster, west | 113.49 | 61.31 | 256.57 |
| NAW | Near surface array, west | 112.25 | 63.90 | 256.70 |
| NA3 | 50 cm tubing cluster, east | 153.80 | 78.03 | 255.68 |
| NA4 | 25 cm tubing cluster, east | 154.82 | 81.51 | 255.47 |
| NAE | Near surface array, east | 152.38 | 80.97 | 255.53 |
| VENT1 | Vent well | 130.74 | 74.58 | 256.25 |
| VENT2 | Vent well | 129.29 | 79.32 | 256.30 |
| SPARGE1 | Sparge well | 127.71 | 76.13 | 256.30 |
| CONT | Control | 452.62 | 313.21 | 244.12 |
| SPK1 | Thermocouple array | 144.78 | 73.74 | 255.92 |
| SPK2 | Grain size distribution | 106.44 | 82.40 | 257.01 |
| SPK 3 | Grain size distribution | 98.64 | 84.18 | 257.01 |
| VP1 | Vapor probe | 131.15 | 78.39 | 256.26 |
| VP2 | Vapor probe | 129.66 | 77.17 | 256.26 |
| VP3 | Vapor probe | 114.57 | 102.99 | 256.26 |

- US Standard No. 100 (0.149 mm)
- US Standard No. 200 (0.074 mm)
- Pan

We placed the soil was placed into the sieves, covered the nest and shook it by hand for 30 seconds to allow all the finer soil to pass the 3/8 inch sieve. The 3/8 inch sieve was inspected visually for small particles retained on the sieve, and any smaller particles were assisted by hand through the 3/8 inch sieve. The 3/8 inch sieve was then removed from the nest (because of limited room in the mechanical shaker) and its contents weighed in a tared porcelain bowl. The rest of the sieves were covered and placed onto the mechanical shaker for six minutes. The 3/8 in. sieve was then removed from the top of the nest, and its contents removed by using a small round brush to clean all the soil out and into a tared porcelain bowl. The soil weight retained was recorded and the process continued down the nest of sieves and into the pan.

Figure 3.1 displays the location of boreholes SPK1, SPK2, and 12AY. We measured particle size distributions in 0.3 or 0.5 m intervals down to the water table in each borehole:

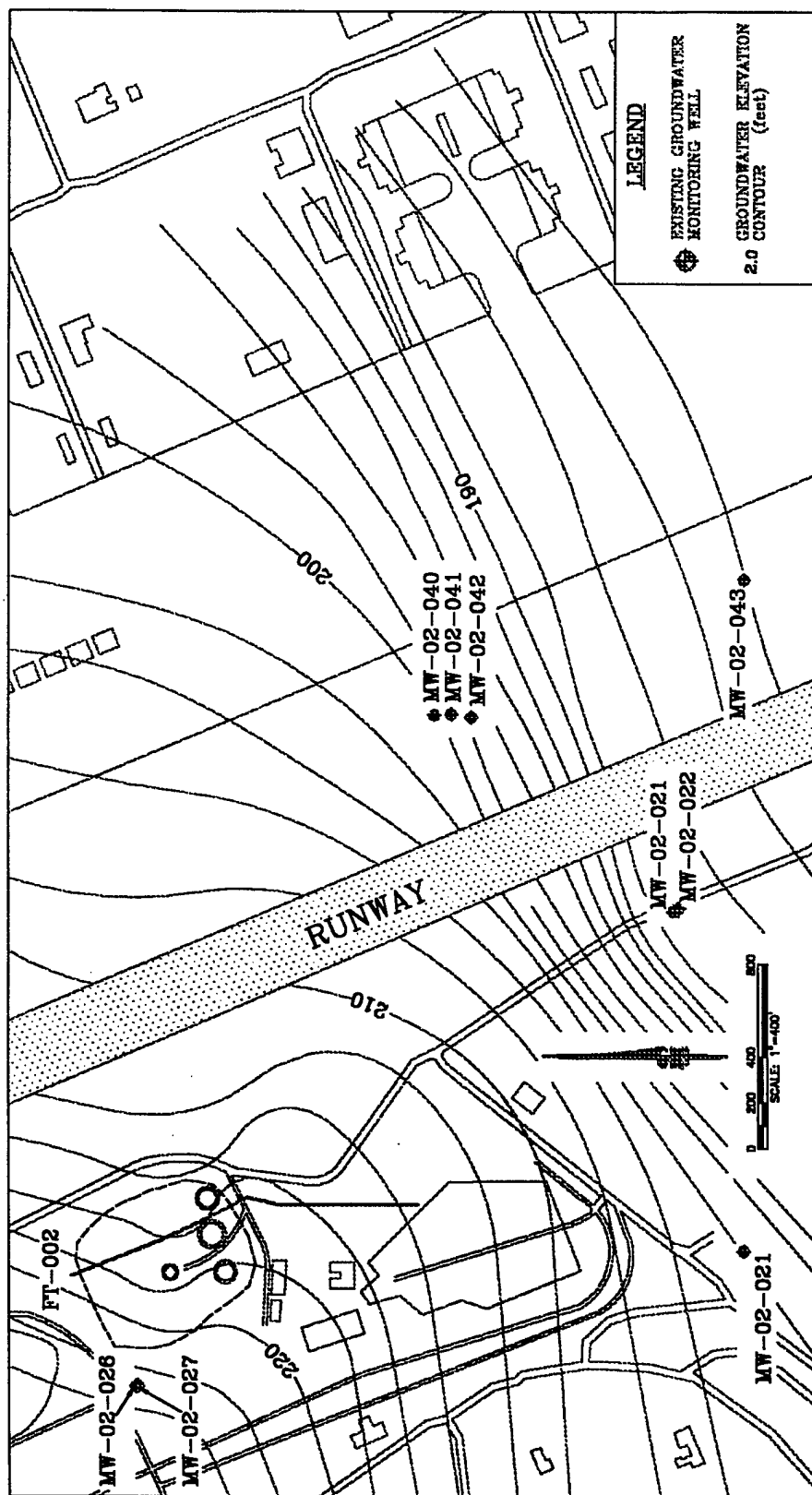


Figure 3.1a Site Plan: Plattsburgh Air Force Base Runway

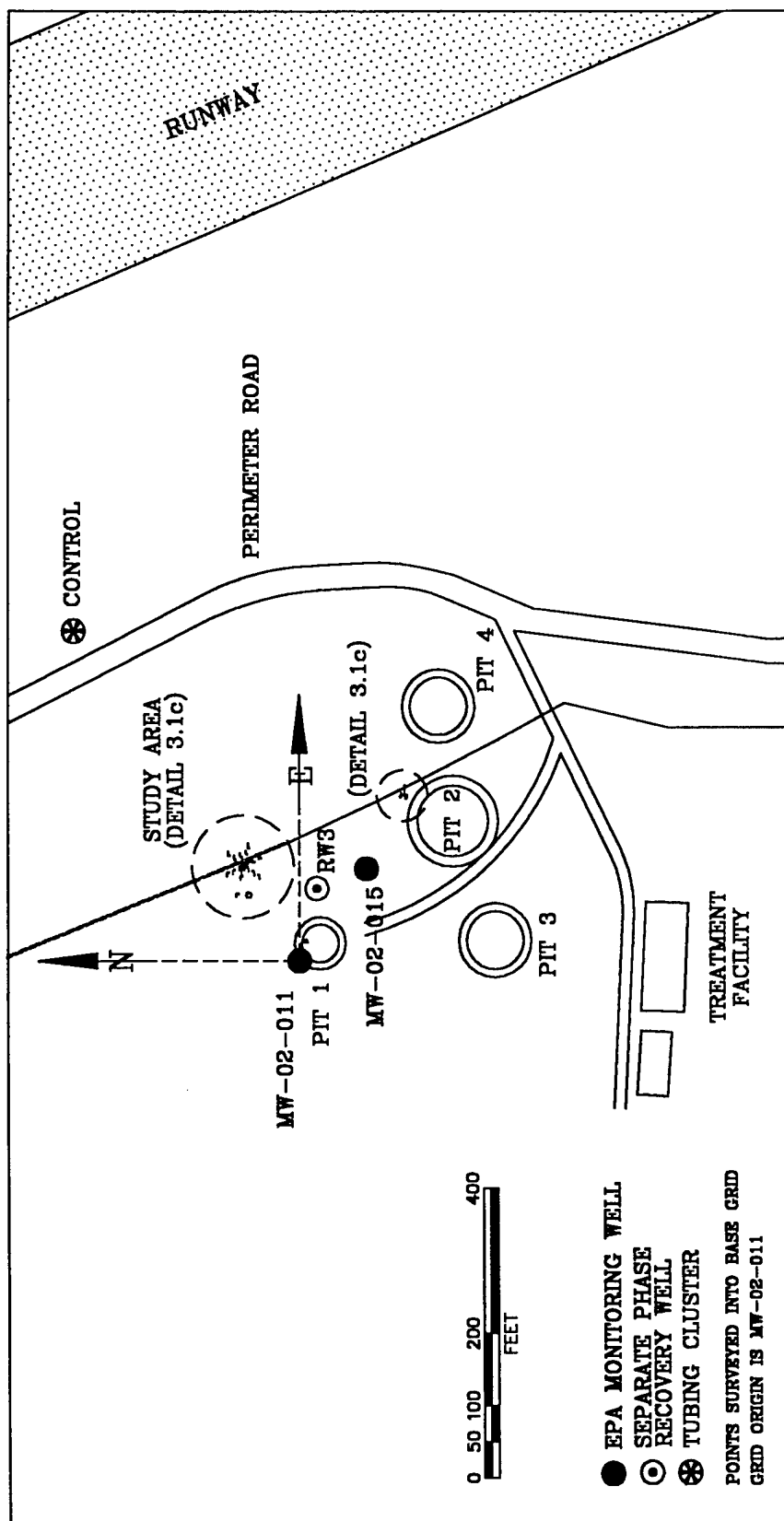


Figure 3.1b Site Plan: Fire Training Area FT-002

TABLE 3.2 SOIL MOISTURE AND LNAPL BOREHOLE DATES AND DEPTH INTERVALS^a

| Borehole | Date | Core Barrel Diameter | Number of samples | Interval, m below surface |
|-----------------|-------------|-----------------------------|--------------------------|----------------------------------|
| 12AA | 9Oct95 | 3 inches | 34 | 0.2-15.2 |
| 12AB | 9Oct95 | 3 inches | 6 | 10.8-14.1 |
| 12AD | 10Oct95 | 3 inches | 25 | 0.1-14.1 |
| 12AG | 10Oct95 | 3 inches | 27 | 0.1-14.0 |
| 12AK | 11Oct95 | 3 inches | 32 | 0.1-14.2 |
| 12AM | 12Oct95 | 3 inches | 22 | 10.7-14.2 |
| 12AP | 12Oct95 | 3 inches | 17 | 10.8-13.6 |
| 12AR | 13Oct95 | 3 inches | 21 | 10.7-14.2 |
| 12AS | 2Dec95 | 3 inches | 63 | 10.7-15.1 |
| 12AT | 1Dec95 | 3 inches | 60 | 7.6-11.9 |
| 12AU | 5Jun96 | 3 inches | 22 | 11.7-14.9 |
| 12AV | 5Jun96 | 3 inches | 35 | 10.7-14.9 |
| 12AW | 5Jun96 | 3 inches | 33 | 10.7-14.7 |
| 12AX | 6Jun96 | 3 inches | 27 | 1.6-11.0 |
| 12AY | 6Jun96 | 2 inches | 18 | 11.0-13.5 |
| 12AZ | 7Jun96 | 3 inches | 46 | 10.7-16.1 |
| 12BA | 7Jun96 | 3 inches | 35 | 10.8-16.1 |
| 12BB | 19Aug96 | 3 inches | 34 | 0.1-14.5 |
| 12BF | 20Aug96 | 2 inches | 33 | 10.7-14.4 |
| 12BI | 21Aug96 | 2 inches | 25 | 11.3-14.2 |
| 12BO | 22Aug96 | 2 inches | 22 | 11.1-14.1 |
| VENT1 | 30Nov95 | 3 inches | 49 | 10.7-12.9 |
| VENT2 | 30Nov95 | 3 inches | 29 | 10.7-13.0 |
| SPARGE1 | 1Dec95 | 3 inches | 70 | 10.7-14.9 |

^aTwenty gm samples stored in serum bottles. Borehole logs are in Appendix I.

- Borehole SPK1 - 33 depths
- Borehole SPK2 - 25 depths
- Borehole 12AY - 50 depths

3.1.3 Soil Moisture

We observed a series of soil moisture profiles through the unsaturated zone and capillary fringe as part of the separate phase petroleum profile sampling at Plattsburgh. Table 3.2 lists the dates, depth intervals, and number of sampling points comprising the moisture (and LNAPL) data base. Logs for these boreholes are listed in Appendix I. Ten mL disposable syringe barrels (Becton Dickinson) were used to withdraw 10 gm samples from the pared face of a core barrel extruded in the field. Figure 3.2 displays the extruder, which consists of a 6.2 cm diameter piston with a 1.1 m stroke, driven hydraulically by a 4 horsepower Honda gasoline power

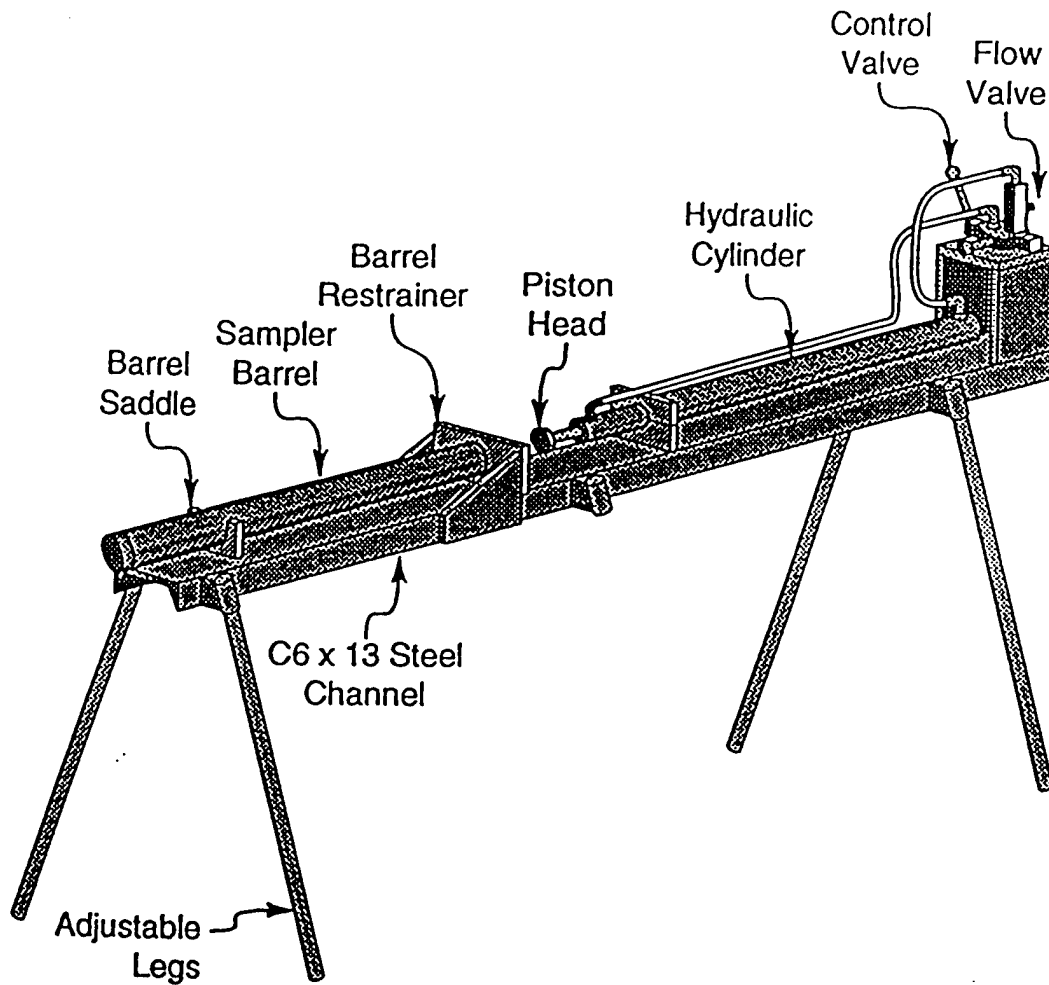
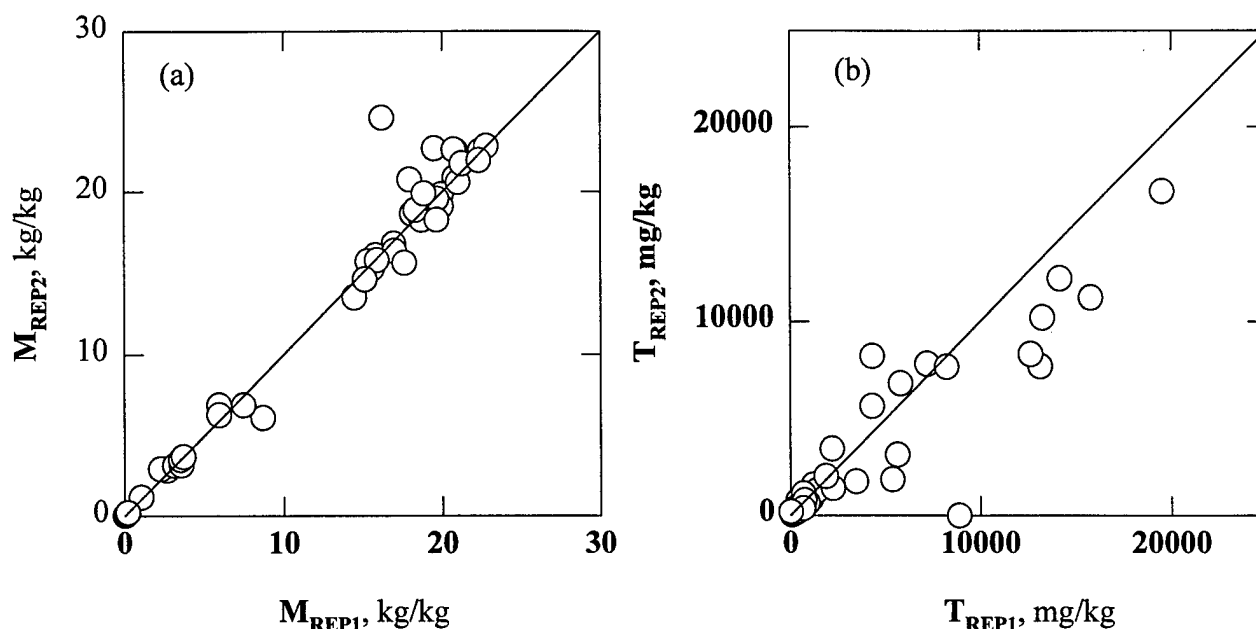


Figure 3.2 Core Barrel Extruder

generator. We control the extruder with a 3 position detente style valve with flow control. The piston is mounted on a C6 x 13 steel channel, equipped with adjustable iron pipe legs and a steel barrel saddle. The upper end of the core barrel is threaded into a threaded gusset barrel restrainer that provides a reaction force to the extruding friction.

The moist samples were stored in preweighed, dried, 20 mL serum bottles with Teflon septa and plastic screwcaps for subsequent gravimetric determination of soil moisture content [ASTM (1992c)]. Data are reported as mass based moisture content M

$$M = \frac{\text{mass} \cdot \text{moisture} \cdot \text{volume}}{\text{dry} \cdot \text{soil} \cdot \text{mass}} \quad (3.1)$$



Note: Symbols are data, while straight line is perfect precision

Figure 3.3 Replicate Soil Moisture (a) and LNAPL (b) Contents for Serum Bottle Samples

Replicate soil moisture samples were obtained in order to assess the method precision P defined by

$$P = \frac{2|\text{replicate1} - \text{replicate2}|}{(\text{replicate1} + \text{replicate2})} \quad (3.2)$$

Figure 3.3a displays 57 moisture replicates taken over the course of field sampling--the average P of 6% suggests excellent precision in spite of the relatively small soil mass required for vertically resolved sampling in a core barrel.

3.2 Separate Phase Petroleum Content in Solid Core Samples

The determination of the separate phase petroleum content of solid core samples features field sampling, laboratory extraction, and gas chromatographic analysis. The field sampling protocol follows the pioneering work of the Robert S. Kerr Environmental Research Laboratory of the US Environmental Protection Agency [Leach et al. (1988)], and the gas chromatography is a modification of RS Kerr methodology for the analysis of light hydrocarbons [Vandegrift and Kampbell (1988)]. The EPA field and laboratory methods have been demonstrated by the Environmental Engineering Program laboratory of the University of Massachusetts at Amherst

on a peer reviewed [Ostendorf et al. (1991)], EPA audited [Ostendorf et al. (1992)] research project with the RS Kerr Laboratory.

3.2.1 Field Sampling

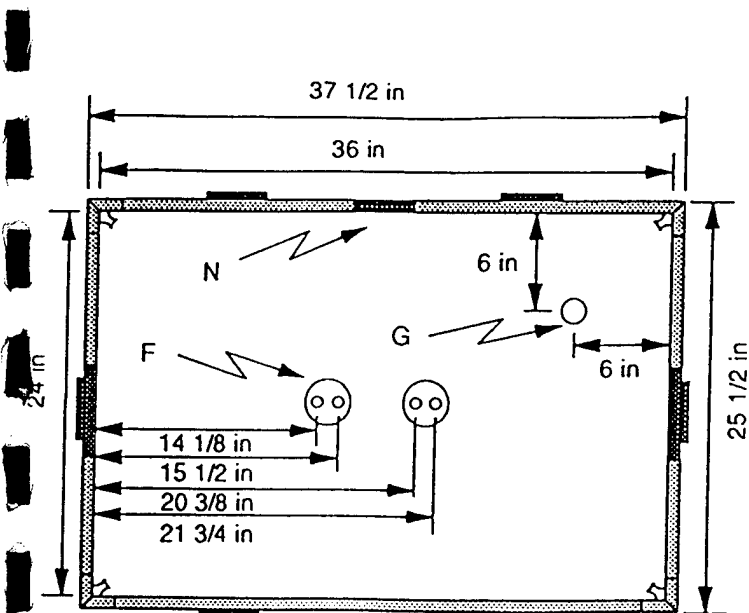
The initial step in obtaining a contaminated soil sample is removal of a soil core from the subsurface. After a prospective sampling location was determined, a steam cleaned, 17 cm outer diameter hollow stem auger was driven by a Central Mine and Equipment Company (CME) 75 drilling rig adjacent to the initial sampling depth. As the augers were driven down, a weighted plug was inserted into the 8.3 cm inner diameter annulus to prevent soil from entering into the hollow portion of the augers. Upon reaching sampling depth, the plug was removed and a 0.46 m long, 7.6 cm OD, soil sampler was inserted into the hollow stem auger. The barrel assembly consisted of four parts:

- A 7.6 cm OD cutting shoe which threaded onto the bottom end of the barrel and cut into the underlying, undisturbed soil
- A plastic soil retainer which fit between the cutting shoe and the barrel and prevented the loss of sample when the barrel was removed from to the surface
- A barrel which contained the soil core after collection
- A drive head which threaded onto the top end of the barrel, connecting it to the drive rods

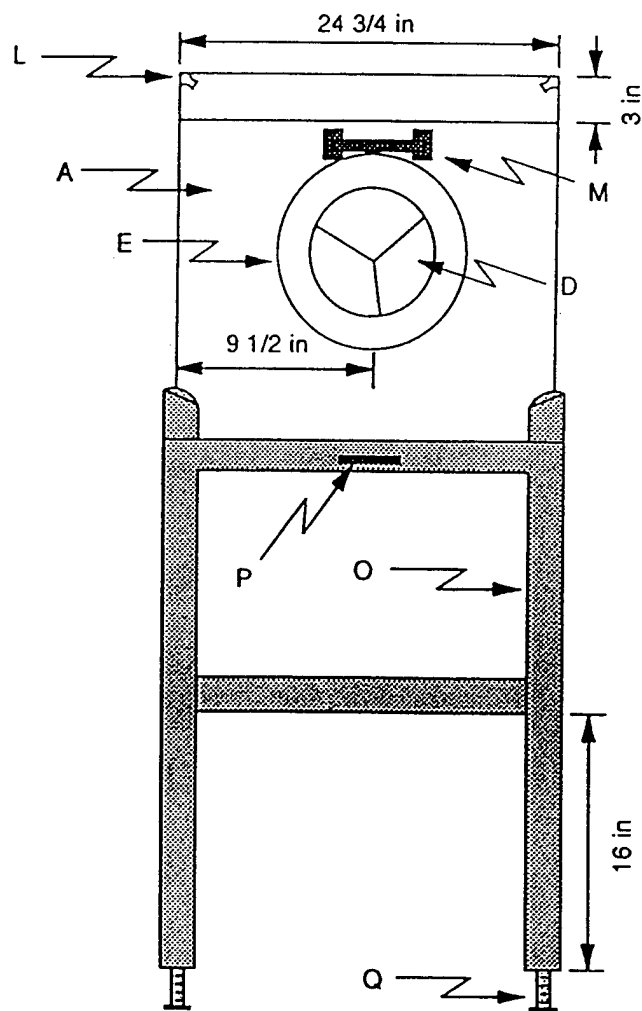
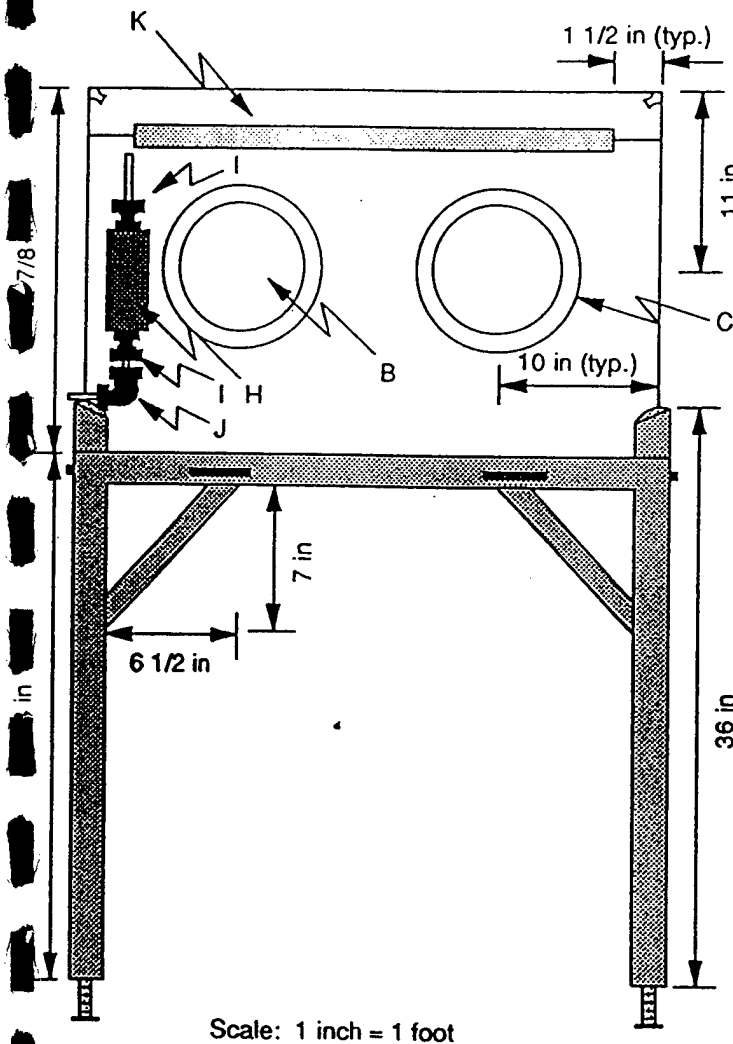
The core barrel, positioned at the sampling depth, was then percussively driven into the underlying soil by a 140 lb automatic hammer with a 76 cm drop. This type of hammer is typically used to run a Standard Penetration Test (SPT) for foundation design, but for this project, hammer blows were counted in order to empirically determine changes in site stratigraphy. Measurements were taken on the portion of the drive rods above the surface, so that the sampler was only driven the 18 inch length of its body. Once this occurred, the sampler was hydraulically lifted to the surface, unscrewed from the driving apparatus, and sent to the next stage of the sampling process. As the sampler with the soil core was at the next stage, a freshly steam cleaned barrel was attached to the drive rods and the whole process began again. This rapid type of soil core acquisition allowed for both continuous or incremental sample collection.

3.2.2 Soil Core Extrusion

The full sampling tube was extruded into a nitrogen filled glove box in accordance with USEPA aseptic field sampling protocol [Leach et al. (1988)]. We first measured sample recovery in the tube, then mounted it horizontally on a hydraulic extruder designed by the University of Massachusetts Geotechnical Engineering Department (Figure 3.2). The cutting shoe was loosened and this end of the sampler was inserted into a nitrogen filled glovebox through a neoprene iris (Figure 3.4). A 6.2 cm piston was then hydraulically pushed into the opening of the sampler opposite the glovebox. Once the shoe and retainer were removed inside, the piston incrementally pushed the soil core into the aseptic sampling environment. This type of soil removal system is intended to minimize sample disturbance.



- A - Lexan (clear polycarbonate): 3/8 in thick for sides and bottom, 1/4 in thick for top.
- B - Two part neoprene gloves and sleeves for 8 inch ports (Fisher Scientific No. 92-045C)
- C - Hand fashioned 3/8 in thick Lexan ring (9 in OD, 8 in ID).
- D - Iris: nine layers of 1/32 in neoprene one layer of 1/16 in neoprene
- E - Hand fashioned 3/8 in thick Lexan rings (12 in OD, 8 in ID)
- F - Sniffer ports: 1/4 in brass bulkhead fittings with wide mouth Mason jar lids.
- G - Purge valve: 3/4 in ID PVC ball valve 3/4 in ID x 1 in nipple & 3/4 in ID bulkhead fitting
- H - 4 scfm direct read flow meter (Cole Parmer No. G-03279-50)
- I - Male connector (Parflex fitting P6MC4)
- J - Elbow union (Parflex fitting P6EU6)
- K - 1 1/2 x 30 in continuous steel hinge.
- L - 8- Brass corner protectors.
- M - 2-6 1/2 in galvanized door pull used as handles.
- N - 1- 5/12 in galvanized door pull to open lid.
- O - 2x2x3/16 inch angle steel.
- P - 6- 5/12 in steel door pulls used for handles
- Q - 6 inch lengths of 5/8 in diameter threaded rod used for adjustable feet.



Scale: 1 inch = 1 foot

Figure 3.4 Field Glovebox for Solid Core Sampling

The glovebox, modeled after a United States Environmental Protection Agency (USEPA) prototype, was designed and built by the University of Massachusetts Environmental Engineering Program. It is constructed of clear Lexan sheets with dimensions of 92x59x64 cm, as shown in Figure 3.4. Other features include two pairs of neoprene access gloves, an iris for inserting soil samplers, a flow meter for regulating nitrogen flow into the box, a nitrogen purge valve, and a headspace sampling port. The glovebox rests in a vertically adjustable stand to facilitate establishment of a level sample plane. The glovebox was purged prior to sampling with prepure grade nitrogen (Merriam-Graves; West Springfield, MA) at a flow rate of 5 ft³/min for 5 minutes. Once sampling commences, the flow was reduced to 0.5 ft³/min. Nitrogen was passed into the glovebox to establish a positive pressure inside the sampling area, thereby excluding contaminated surface air. If biological samples are taken, either nitrogen or synthetic air can be used depending on the type of microbiological study being performed.

Wide mouth, 1 quart, Mason jars (Alltrista Corporation; Muncie, IN) were used as sample collection vessels for the extruded soil cores. These jars were autoclaved and labeled prior to each trip and packed numerically, 24 at a time, into the glovebox before the nitrogen was turned on. The standard size Mason jar was filled 2/3 full with approximately 15 cm of soil core. Sampling in this manner allowed for three sampling points per core. Smaller volume jars (pints and half pints) were used for more resolved vertical separate phase profiles. The extruded section of soil core was introduced into the Mason jar using a trowel that was wiped clean with Kimwipes between samples. Accurate field logging, linking borehole ID to depth to jar ID was essential at this step of the sampling procedure.

3.2.3 Headspace Determination and Subsampling

We measured the total hydrocarbon vapor pressure in the Mason jar headspace to estimate the degree of volatility of the separate phase product residing in the soil, and thus guide the acquisition of solid core samples. The glovebox was equipped with a Mason jar lid with Swagelok penetrations, globe valve, and a Teflon transfer line to the Bacharach TLV sniffer to facilitate headspace sampling. We screwed the filled jar into the lid, opened the globe valve, and pulled headspace into the TLV sniffer. It took approximately 30 seconds for the meter to measure the headspace of the jar. The in-line globe valve was then closed, the meter allowed to rezero, and the Mason jar recapped and set aside for further processing.

The headspace hydrocarbon vapor partial pressure (p_G) correlates positively with separate phase petroleum content (T) for solid core samples from the contaminated capillary fringe. Figure 3.5 displays the Mason jar headspace for four typical contaminated boreholes--headspaces as high as 6,000 ppm correlated with soil as contaminated with as much as 26,000 mg petroleum/kg dry soil. This finding is consistent with other field results, as summarized in Figure 3.6 [Ostendorf et al. (1996)]. We compare headspace correlation for weathered LNAPL contaminated soils from three field sites:

- Figure 3.6a - Gasoline/diesel fuel (high volatility)
- Figure 3.6b - Fuel oil (low volatility)

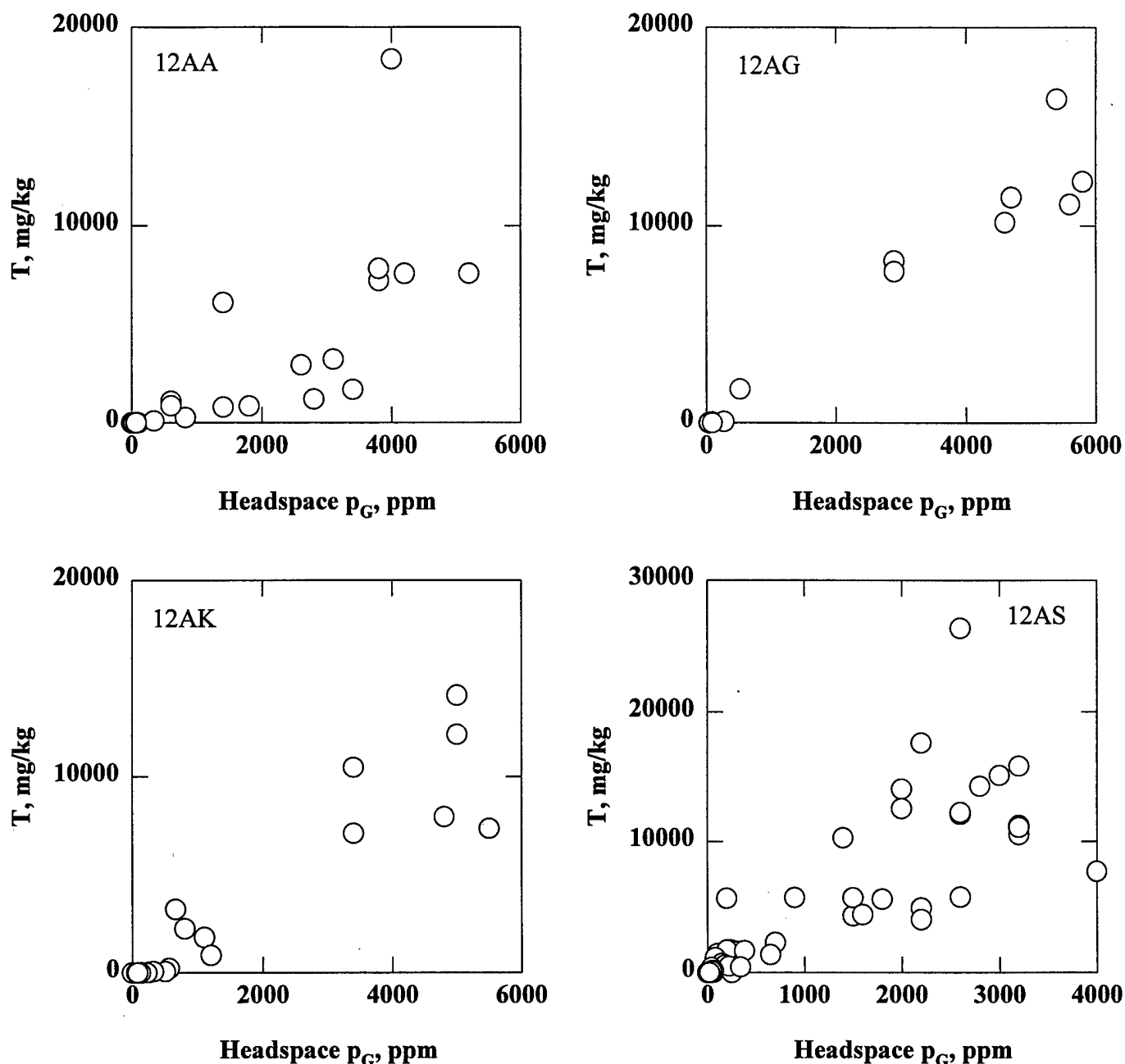


Figure 3.5 Separate Phase Petroleum Content (T) vs Mason Jar Headspace (p_G) for Typical Plattsburgh Boreholes

- Figure 3.6c - Aviation gasoline (highest volatility)

The weathered separate phase aviation gasoline yields the highest headspace pressures, T values less than 5,000 mg/kg exhibit p_G levels in excess of 10,000 ppm into the Mason jar headspace. Weathered JP-4 and the gasoline/diesel fuel mixture yield a weaker (but still readily detectable)

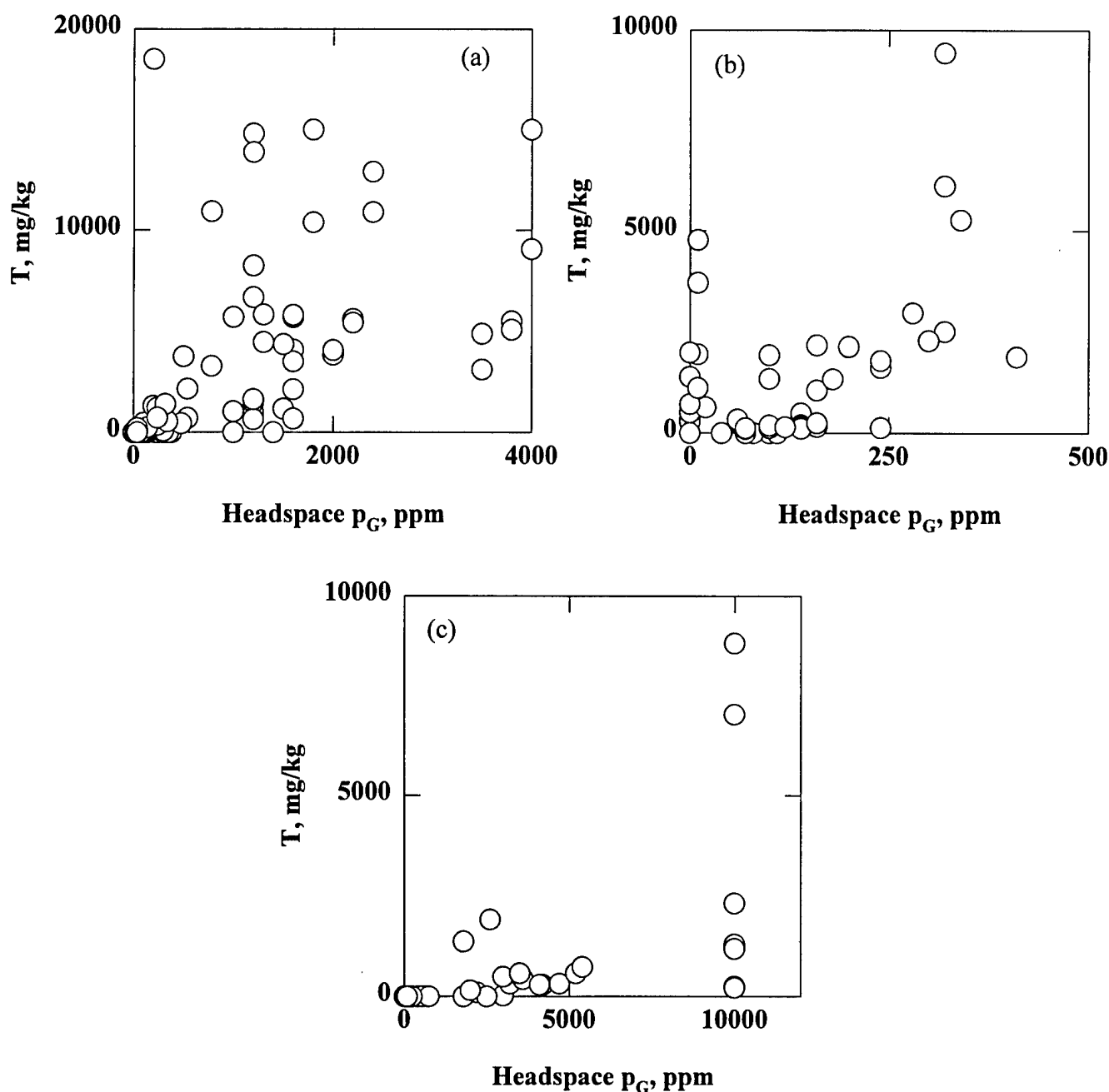


Figure 3.6 Separate Phase Petroleum Content (T) vs Mason Jar Headspace (p_G): (a) Gasoline/Diesel Fuel, (b) Fuel Oil, (c) Aviation Gasoline [Ostendorf et al. (1996)]

headspace, as indicated by Figures 3.5 and 3.6a. The fuel oil generates a very weak response by virtue of its low volatility. Indeed, Figure 3.6b suggests that a number of Mason jars containing several gms fuel oil/kg dry soil do not exhibit any headspace hydrocarbon vapor pressures at all.

We began to subsample in the field upon completion of drilling for the day. core barrel extrusion for each day in the afternoon of the samplined once the core barrel acquisition step

was complete and all of the soil had been sampled into respective jars. This step began by loading the glovebox with the following items:

- Twenty four Mason jars containing contaminated soil samples that were collected that day.
- A rack of 50 cleaned, autoclaved, and labeled 20 mL EPA vials (Kimble; Owens, IL) with Teflon coated silicone septa for separate phase analysis. Each vial was prefilled in the laboratory with 3 mL of GC Resolve Methylene Chloride (CH_2Cl_2) (Fisher Scientific; Pittsburgh, PA) and 5 mL of organic free water and weighed to determine its presampling mass.
- A rack of 50 cleaned and labeled 20 mL EPA vials (Kimble; Owens, IL) with Teflon coated silicone septa for moisture content analysis.
- Cleaned and autoclaved 10 cc syringe barrels with removed tips (Becton Dickinson Corporation; Franklin Lakes, NJ).

The glove box was again purged and filled with nitrogen, as in the extrusion step. When this was complete, an approximate 15 g sample was taken from each jar using a 10 cc syringe barrel and deposited into a respective subsampling vial filled with methylene chloride and water. The threads of the vial were then wiped clean, the cap tightened, and the vial replaced in the rack. Using the same 10 cc syringe barrel, a 30 g soil sample was deposited into a corresponding moisture content vial. To prevent cross contamination, a new syringe barrel was used for each new jar. Careful records needed to be taken down throughout this phase of the sampling because it was simple to mix up the jar ID and vial ID within the confines of the glovebox. After subsampling was complete, the filled methylene chloride and moisture content vials were packed with ice in coolers for transportation back to the UMASS Environmental Engineering Lab, where they were stored at 4°C in sample refrigerators until the laboratory extraction and analysis steps. The sample jars were also brought back to UMASS and stored in a well ventilated area for future soil grain size analysis.

Since the sampling jars contain approximately 15 cm of soil core, the separate phase and moisture content profiles possess a data point every 15 cm of depth. Therefore, the four steps involved in this field sampling protocol produce a relatively precise representation of the subsurface in a short sampling period.

3.2.4 Separate Phase Petroleum Extraction

The extraction process commenced once the field samples are transported to the laboratory. First, the subsampling vials were weighed in order to calculate the wet mass of the soil sample. The difference between the pre and post sampling masses provided this value. They were then horizontally shaken on a modified shaker table (Eberbach Corporation; Ann Arbor, MI) for 20 minutes. This step allowed the solvent to penetrate into the pores of the soil, causing continuous separate phase and any trapped petroleum ganglia to dissolve into it. Effective agitation allowed the small 3 mL volume of solvent to extract the contamination efficiently.

After shaking, the vials were each centrifuged at 3000 rpm for 1 minute in a International

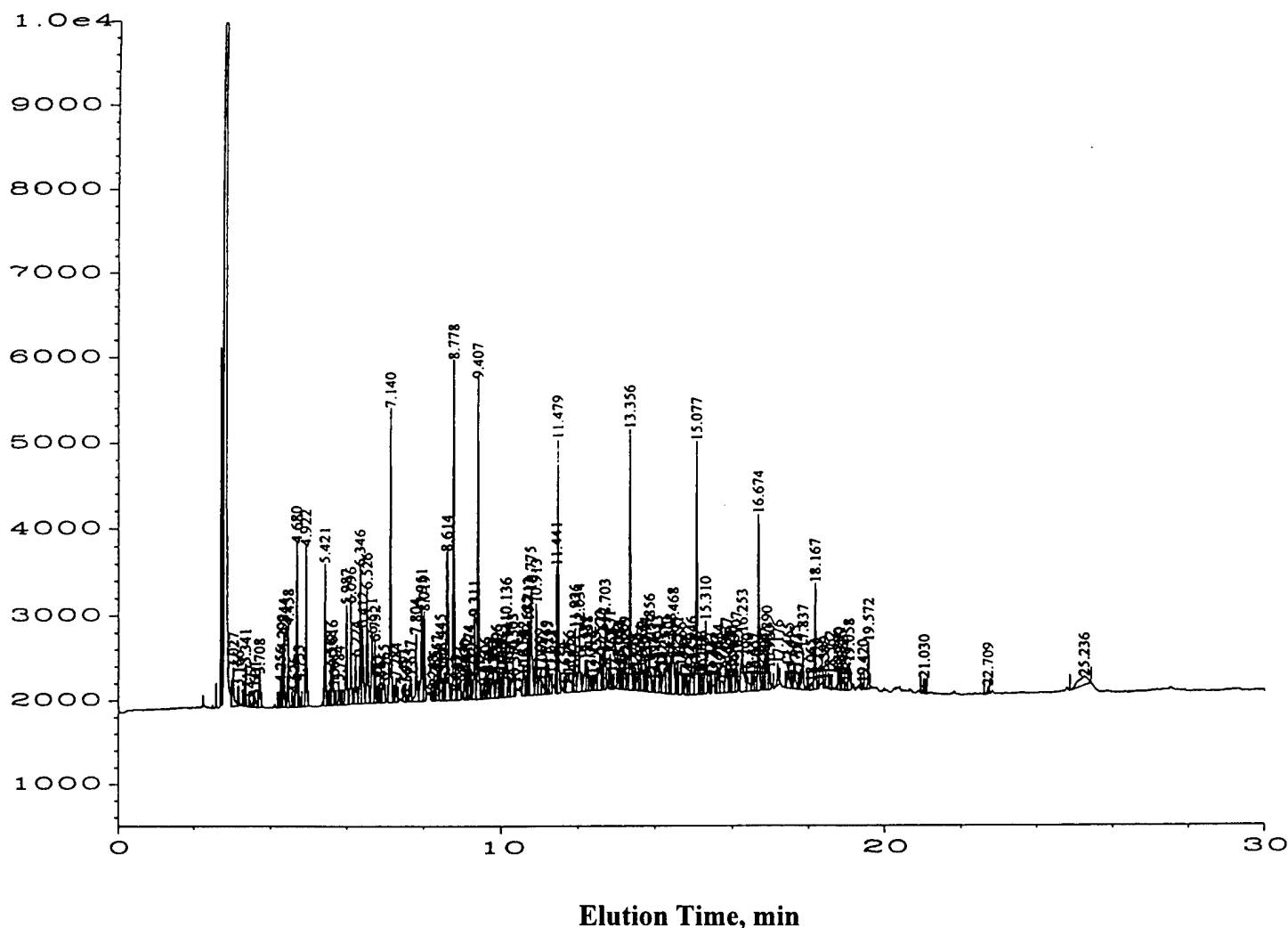


Figure 3.7 Typical FID Chromatogram for LNAPL Standard

Equipment Corporation CI2 centrifuge (International Equipment Corporation; Boston, MA). This process separated the soil, water and methylene chloride with dissolved hydrocarbons into three different density layers. In some cases where silty soil layers were encountered, the vials need to be manually tapped so that the isolated bubbles of solvent coalesced into one large lens. A degree of skill was necessary on the part of the analyst when extracting from fine grained soils. Once the solvent with dissolved hydrocarbons was separated from the other media found in the vial, a 3 cc syringe with a 5.1 cm, 21 gauge, bevel tipped needle (Becton Dickinson Corporation; Franklin Lakes, NJ) punctured the vial's septa. After probing for the solvent lens with the needle, the material was withdrawn from the vial using the syringe. Typically, a 1 to 3 mL sample was obtained during this step.

Any remaining water was extracted from the sample by passing it through a glass pipette (Fisher Scientific; Pittsburgh, PA), filled with 10-60 mesh, anhydrous sodium sulfate (Na_2SO_4) (Fisher Scientific; Pittsburgh, PA), and glass wool (Supelco; Bellefonte, PA) caps. The water in

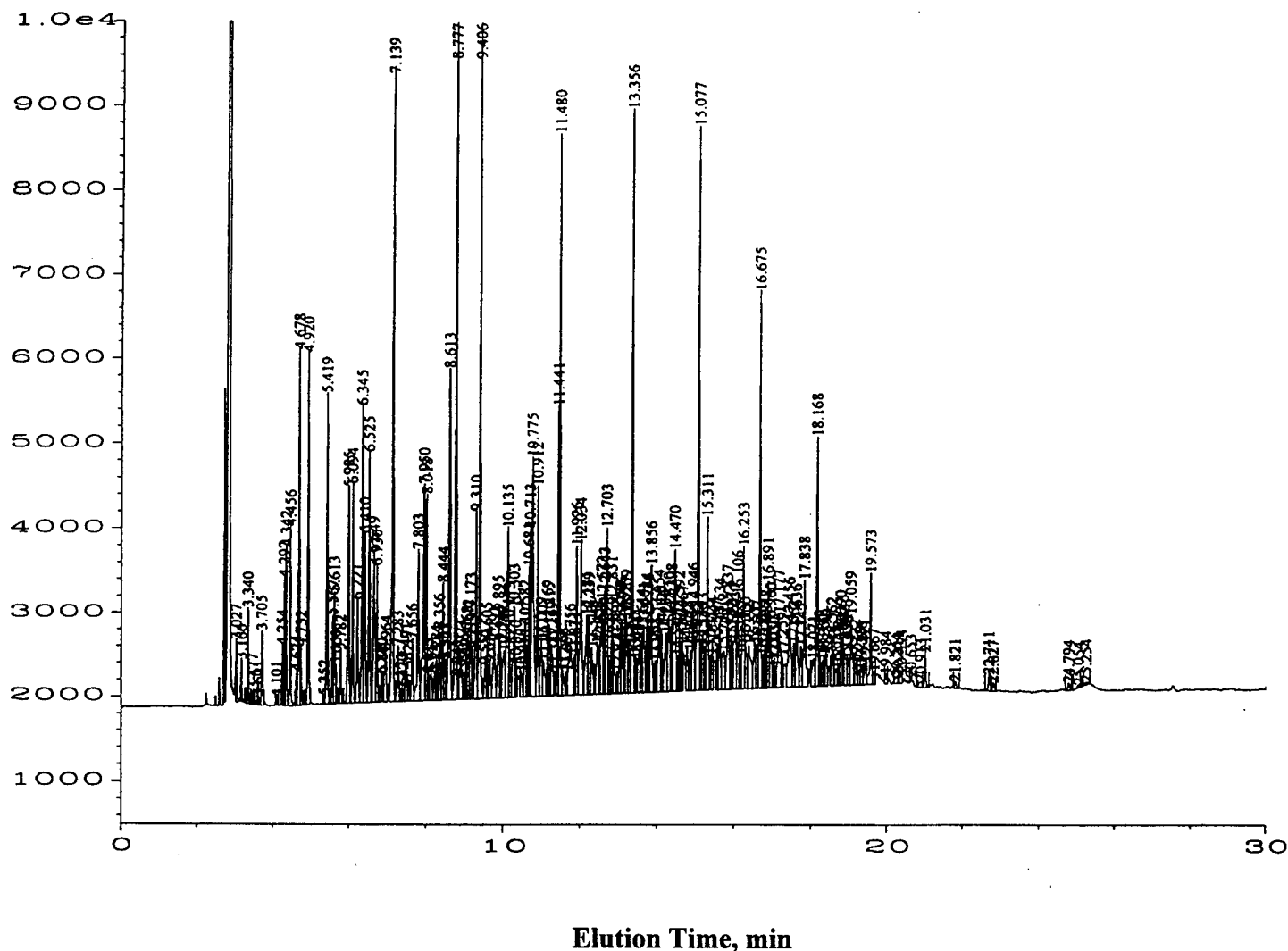


Figure 3.8 Typical FID Chromatogram for LNAPL Extract

the sample has a greater affinity for sodium sulfate than the solvent, thus it adsorbed to the material. Another positive point of the Na_2SO_4 trap was its ability to filter any silty material drawn into the syringe during the extraction step. Each sample required a new drying column, thus a number of columns must be made before each field trip. These traps were stored in sealed, desiccant filled Mason jars prior to use. We collected the pure methylene chloride with dissolved hydrocarbon effluent from the Na_2SO_4 trap into two extraction vials, each with the corresponding subsampling vial's ID. The first vial was a 2 mL, Target autosampling vial with a 250 μL insert and Teflon coated silicone septa (Hewlett Packard; Wilmington, DE). After the microvial was filled, a 2 mL, Target vial with Teflon coated silicone septa (National Scientific Company; Lawrenceville, GA) was used to collect the remaining sample. This reserve sample was necessary if duplicate analyses were required because the original sample's integrity was compromised after the autosampling vial's septa was punctured. After processing, the extraction vials were stored in a sample refrigerator at 4°C until analysis.

3.2.5 Gas Chromatographic Analysis of Solid Core Extracts

We used an HP 5890 Series II gas chromatograph for nearly all of the separate phase petroleum content determinations (Hewlett Packard; Wilmington, DE). It possesses an HP automatic liquid sampling system consisting of a controller, an injector module and a tray module, with data acquisition by an HP Series II Chemstation software package. All hardware settings and data manipulation activities are also controlled through this program.

The gas chromatograph is outfitted with a flame ionization detector (FID) connected to an HP-5 capillary column (Hewlett Packard; Wilmington, DE). The column has a length of 30 meters, an inner diameter of 0.32 mm, and a 0.25 μm thick, methyl silicone stationary phase with 5% phenol. Zero grade nitrogen (Merriam-Graves; Springfield, MA) is used as a carrier gas, detector makeup gas, and septum purge gas. The carrier gas flow through the column is set at 2.0 mL/min by an electronic pressure control system, while makeup gas and septum purge flows are set at 28 mL/min and 3 mL/min respectively. The nitrogen flow entering the injector is split 100 to 1 prior to entrance into the capillary column. Control of the auxiliary gas flows is monitored by two external regulators which limited the pressure of the zero grade air (Merriam-Graves; Springfield, MA) entering the machine to 37 psi (314 mL/min) and the zero grade hydrogen (Merriam-Graves; Springfield, MA) to 18 psi (36 mL/min). Finally, all of the gases are cleansed of moisture upon entering the gc by scrubbers (Hewlett Packard; Wilmington, DE) placed in-line with each stream. Oxygen is also removed from the nitrogen flow by an oxygen scrubber positioned in series with the flow's moisture scrubber. The 29.5 minute gc temperature program varied oven temperature from 35°C for the first three minutes of the run, to an increasing rate of 10°C/min for 16.5 minutes, to a final temperature of 200°C for 10 minutes. Injector and detector temperatures were set at 300°C and 325°C respectively. This program provided the best total petroleum hydrocarbon results for the types of product found at the study site. All of the hydrocarbon constituents eluted within the desired analysis time period without any build up in the column.

A two μL sample of refined methylene chloride (CH_2Cl_2) and dissolved hydrocarbon was injected into the split mode injector using a 10 μL HP autosampler syringe (Hewlett Packard; Wilmington, DE). The ability of the device to split the sample enabled sample mass to be injected into the gc without fear of column clogging or detector overload. The syringe was autocleaned after each run by rinsing it with CH_2Cl_2 and discharging the rinse fluid into a waste container. This solvent wash was changed after every 24 hours of analysis to prevent contamination. A new HP predrilled injector septa (Hewlett Packard; Wilmington, DE) was installed after every 75 to 100 gc injections. The underside of the septa was protected by the 3 mL septum purge flow of nitrogen which prevented petroleum products from building up, thereby alleviating random desorption into the carrier gas stream.

All analog output from the gas chromatograph was stored as digital data in a data file set up by the Chemstation software program. This fluctuating data was then integrated in the data analysis section of the program, yielding a chromatogram with tabulated peak information. The

**TABLE 3.3 LNAPL STANDARD CONCENTRATIONS FOR SOLID CORE ANALYSES
OCTOBER 1995 ANALYSES**

| Standard ID (μ l Sep Phase) | Concentration ^a | FID Area ^b |
|-------------------------------------|----------------------------|-----------------------|
| 100 | 111.11 | 4425363 |
| 50 | 52.63 | 2149720 |
| 10 | 10.10 | 423793 |
| 5 | 5.03 | 173056 |
| 1 | 1.00 | 22827 |
| 0.5 | 0.50 | 8424 |

^a μ L separate phase/mL methylene chloride.

^bexcludes the methylene chloride solvent peak.

integration abilities of the machine are quite varied and were easily manipulated to suit the needs of the research. This analysis utilized a simple integration method which did not include the area under the solvent peak into the total chromatographic area calculation. Results of the data analysis were then stored in both digital and hardcopy format. Figures 3.7 and 3.8 show typical chromatograms for an LNAPL standard and an LNAPL sample extract, respectively. The chromatograms contain numerous peaks, indicating a blend of one hundred or more petroleum hydrocarbons in the separate phase JP4 jet fuel spill.

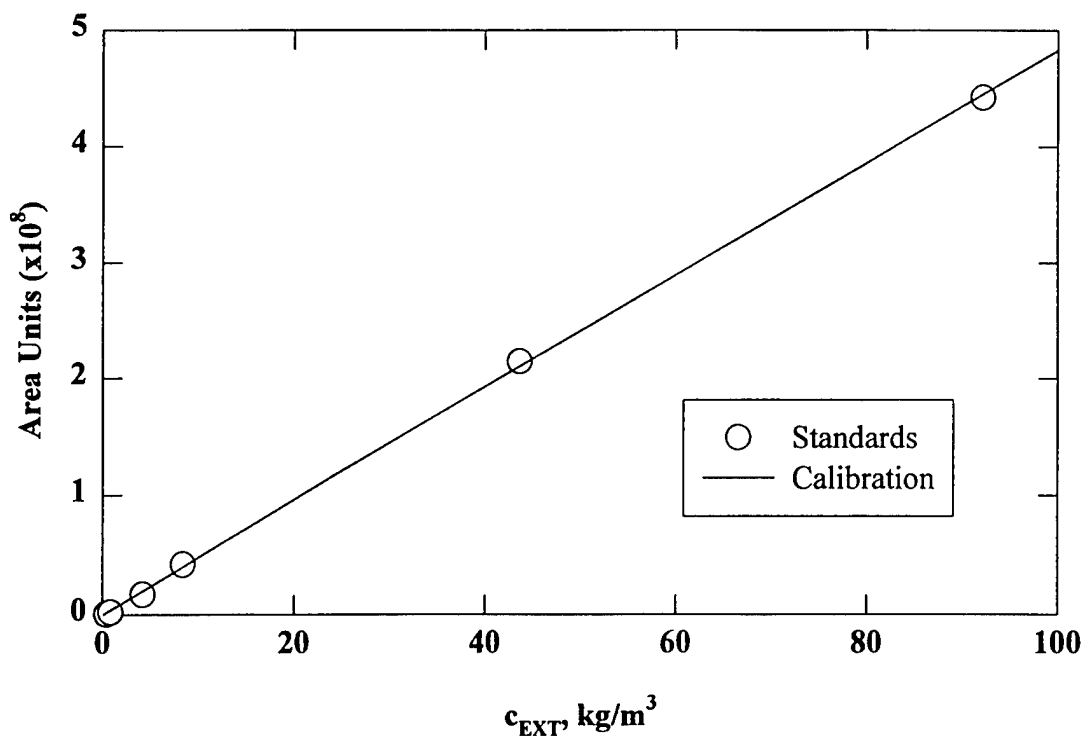
3.2.6 Separate Phase Petroleum Calibration Standard

We collected a separate phase sample from a separate phase recovery well RW3 on 28 June 1995 to serve as a separate phase total petroleum hydrocarbon standard for the four batches of Plattsburgh soil core samples. The well is adjacent to the UMASS study area, as shown in Figure 3.1. The sample was contained in a 20 mL EPA vial with Teflon coated silicone septa, wrapped in Parafilm and stored in an explosion proof refrigerator at 4°C in order to preserve the integrity of the standard. Six methylene chloride/LNAPL standard solutions of varying concentrations were injected into the gas chromatograph, generating a separate phase LNAPL calibration curve for each batch of samples. Table 3.3 and Figure 3.9 present the standard injections and FID responses for the October 1995 analyses. The response factor RF and intercept IN of the calibration curve convert total chromatographic area (excluding the methylene chloride solvent area) to extract concentration c_{EXT} .

$$c_{EXT} = \rho_L [RF(\text{area} \cdot \text{units}) + IN] \quad (\rho_L = 830 \text{ kg/m}^3) \quad (3.3a)$$

$$c_{EXT} = \frac{\text{kg} \cdot \text{LNAPL}}{\text{m}^3 \cdot \text{extract}} \quad (3.3b)$$

The JP4 jet fuel liquid density ρ_L cited in Equation 3a was measured by weighing a known



$$RF = 2.50 \times 10^{-8} \text{ area units}^{-1}$$

$$IN = 9.53 \times 10^{-5}$$

Figure 3.9 Standard Calibration Curve for 1995 October LNAPL Analyses

volume of RW3 product on a Mettler H54 analytical balance (Mettler; Hightstown, NJ). The LNAPL content T of the solid core samples is computed from the known extract concentration

$$T = \frac{\text{mass} \cdot \text{LNAPL}}{\text{mass} \cdot \text{dry} \cdot \text{soil}} \quad (3.4a)$$

$$T = \frac{c_{EXT} V_{EXT}}{M_{DRY}} \quad (V_{EXT} = 3\text{mL}) \quad (3.4b)$$

with measured dry soil mass M_{DRY} and methylene chloride extract volume V_{EXT} .

3.2.7 Method Detection Limit and Field Spikes

The method detection limit (MDL) was determined for LNAPL analyses, with the results summarized in Figure 3.10. Seven low strength injections of 0.03% separate phase standard

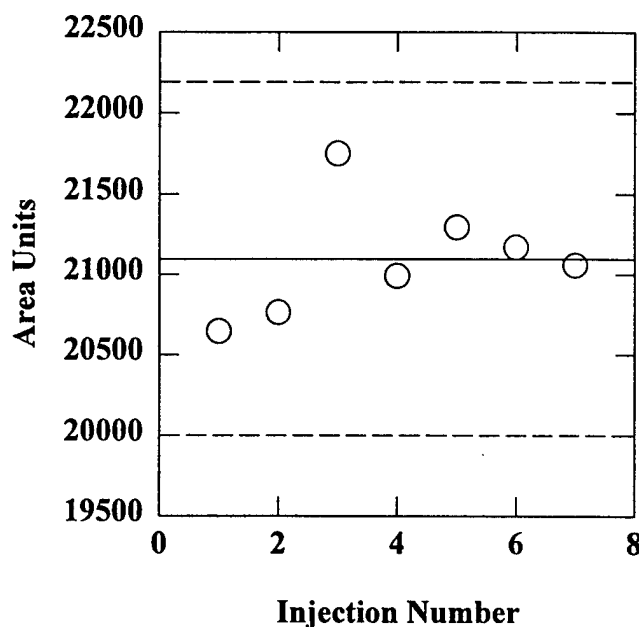


Figure 3.10 Method Detection Limit Study for LNAPL Analyses

were injected successively into the gas chromatograph, and the MDL was computed in accordance with [Taylor (1987)]

$$\delta_{MDL} = \frac{1}{N} \sum_{N} \text{area} \cdot \text{units} \quad (\text{N samples}) \quad (3.5a)$$

$$\sigma_{MDL} = \sqrt{\frac{1}{N} \sum_{N} \text{area} \cdot \text{units}^2 - \delta_{MDL}^2} \quad (3.5b)$$

We measured a sample mean of 21,096 and a standard deviation about the mean of 365 area units. The latter corresponds to a method detection limit MDL of

$$MDL = 3\sigma_{MDL} \quad (3.6a)$$

$$MDL = 1095 \text{ area} \cdot \text{units} \quad (3.6b)$$

$$T_{MDL} = 1 \frac{\text{mg}}{\text{kg}} \quad (3.6c)$$

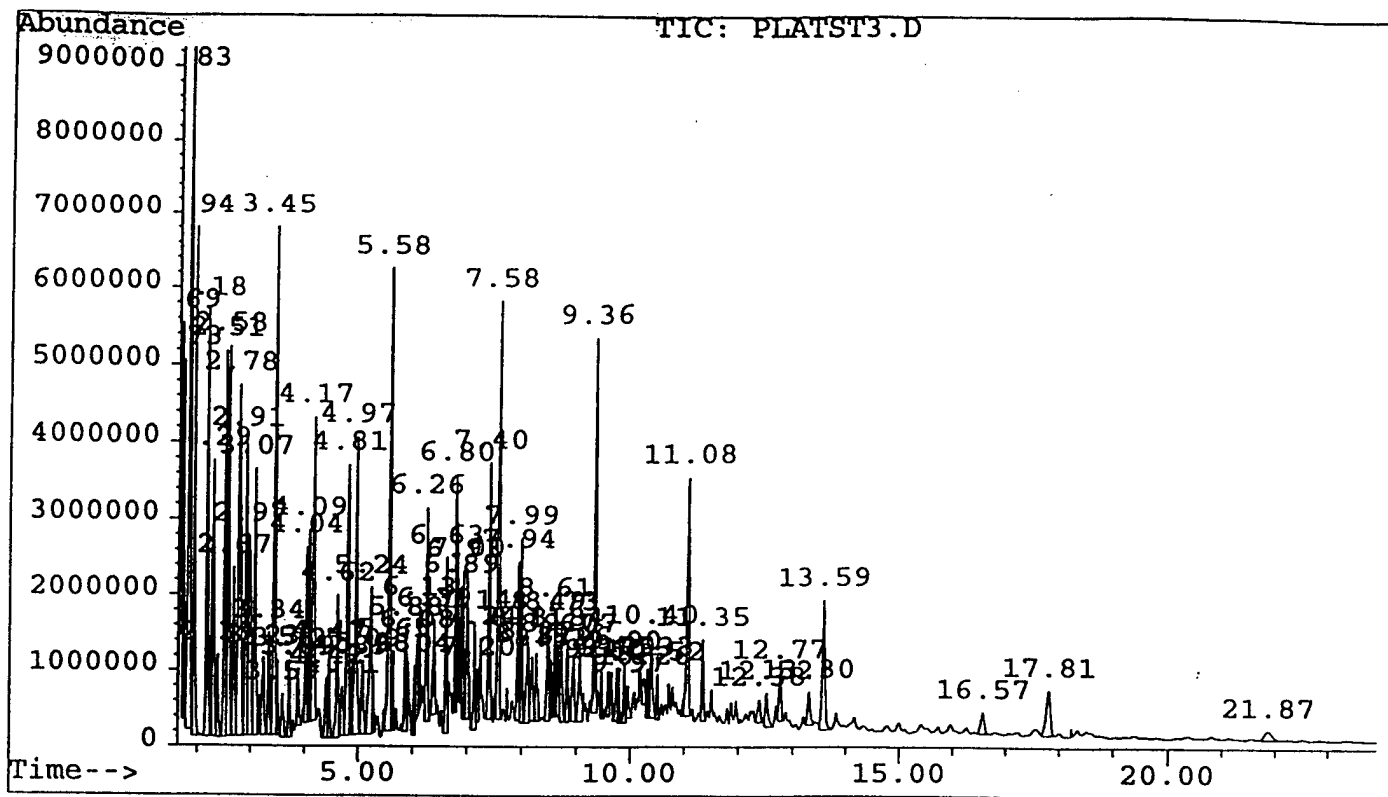
The separate phase method detection limit T_{MDL} cited in Equation 3.6c is based on a representative dry soil mass of 0.02 kg. It is four orders of magnitude smaller than the maximum observed LNAPL concentration, so that the gc/FID methodology is quite accurate.

TABLE 3.4 LNAPL FIELD SPIKE RECOVERIES

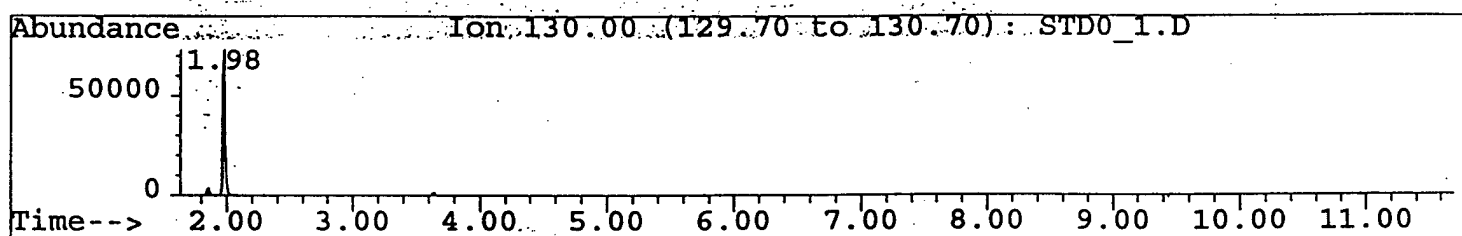
| Dates | Spike Volume, μL | Recovery, % | Dates | Spike Volume, μL | Recovery, % |
|--------------------|--|------------------------|-------------------|--|------------------------|
| 9-13Oct95 | 50 | 105 | 5-7Jun96 | 50 | 73 |
| | 100 | 117 | | 100 | 105 |
| | 150 | 107 | | 200 | 111 |
| | 200 | 100 | | 50 | 104 |
| | 50 | 114 | | 100 | 106 |
| | 100 | 98 | | 200 | 114 |
| | 150 | 109 | | | |
| | 200 | 99 | | | |
| 30Nov-Dec95 | 50 | 109 | 20-22Aug96 | 100 | 113 |
| | 100 | 84 | | 60 | 106 |
| | 150 | 93 | | 50 | 102 |
| | 200 | 92 | | 30 | 101 |
| | 50 | 108 | | 20 | 94 |
| | 100 | 112 | | 10 | 84 |
| | 150 | 109 | | 5 | 65 |

We also ran replicate injections of the same extract as part of the quality assurance program associated with LNAPL profiling. Replicate injection precision, defined by Eq. 3.2, is 6% for the October 1995 samples and 4% for the December 1995 samples: the gas chromatograph is very precise. Figure 3.3b lists sample results for 37 replicates, consisting of LNAPL determinations in soil subsamples withdrawn by syringe barrel from the same (quart sized) Mason jar. A precision of 39% is exhibited by these replicates, reflecting the scatter inherent in field sampling from a 15 cm interval of the borehole. Much of the scatter is attributable to a few anomalous replicates. The outlier at the bottom of Figure 3.3 exhibits a P of 200% for example, and the average precision would be 34% without it. We note that the method would likely be more precise (smaller P) for smaller Mason jars and larger subsample masses, but the logistics of LNAPL profiling of many boreholes precluded this.

Field spiking is a QA/QC technique that monitors the extraction protocol and sample transportation/storage conditions. We spiked blank field samples of known mass and moisture content with 20 μ L of methylene chloride standard solutions of 0.04% strength in the field during drilling operations. After injection, the spike was stored, transported, extracted, and analyzed in identical fashion to the other field samples. The spike recovery is the ratio of the observed T to the original T. Table 3.4 summarizes the average separate phase petroleum spike recovery for the four trips. The recoveries for the four ranged from 65 to 114% in magnitude with an average value of 101% and a standard deviation of 12%. The high recovery and low standard of deviation indicates that the extraction and storage protocol for the samples was very effective. It also infers that the LNAPL, as well as, the soil types from each site, were well suited for the solvent extraction process implemented in this project.



Ion Chromatograph for Separate Phase Extract



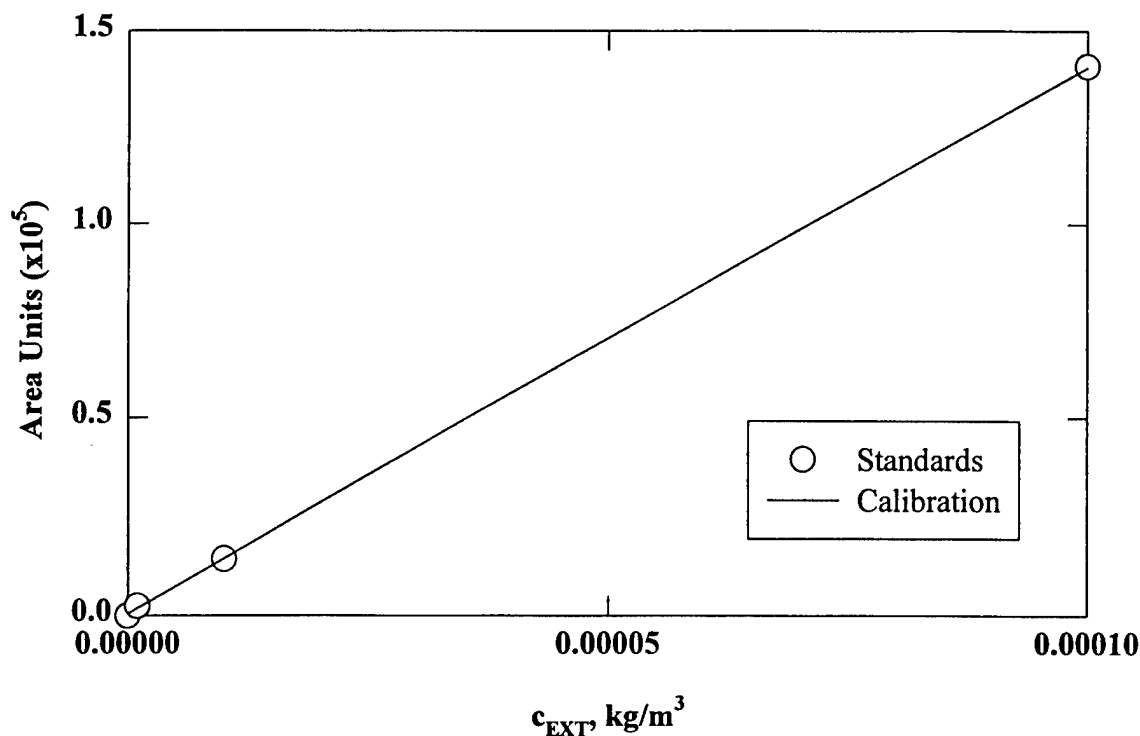
Scan for Trichloroethylene (Mass/Charge Ratio 129.70 to 130.70, 1.98 min Retention Time)

Figure 3.11 Typical GCD Chromatogram of JP4 Jet Fuel Extract

3.3 GCD Analyses and TCE Content

3.3.1 GCD Protocol for TCE Analyses

We measured the separate phase trichloroethylene content T_{TCE} in methylene chloride extracts from 6 of the solid core boreholes discussed in Section 3.2. We withdrew 2.0 μ l of extract from the target vials with a 10 μ l Hamilton Gastight syringe (RN 1701) equipped with a Chaney adaptor and a 26 gage stainless steel needle with beveled tip. The extract was injected into a Hewlett Packard G1800A Gas Chromatograph with mass spectrometer detector (GCD).



$$RF = 7.14 \times 10^{-10} \text{ kg/m}^3\text{-area unit}$$

$$IN = 3.58 \times 10^{-7} \text{ kg/m}^3$$

Figure 3.12 GCD Calibration Curve for TCE

The split/splitless injector temperature was 250°C and a split ratio of 20 to 1 was used, with 1 ml/min zero grade helium used as a carrier gas. The sample was carried into an oven held at 40°C for 4 min, then ramped at 10°C/min to 150°C. The oven was equipped with a 0.32 mm ID, DB5 capillary column 30 m long, featuring a 0.25 μm thick film with crosslinked 5% phenylmethylsiloxane. The mass spectrometer detector was heated to 280°C and scanned over a mass to charge ratio range of 10 to 425. Figure 3.11 displays a typical separate phase extract GCD chromatogram. Appendix VI lists a typical GCD chromatogram for a separate phase extract.

Trichloroethylene was identified by a comparison of observed ionization spectra with Hewlett Packard library spectra, then confirmed by analysis of standard injections of the chlorinated organic. The TCE coelutes with heptane, so that a scan through a mass charge ratio of 130 is used to isolate the compound. A set of separate phase TCE standards was injected into the instrument to develop a calibration curve and response factor similar to Equations 3.3. Figure 3.12 displays a typical calibration curve. The resulting equation for the extract TCE concentration c_{TCE} is

$$c_{TCE} = RF(\text{area} \cdot \text{units}) - IN \quad (3.7)$$

3.3.2 GCD Analysis of Total Hydrocarbons

We also used the GCD to identify major constituents of the separate phase JP4 jet fuel. We analyzed free product sampled from recovery well RW3 (Figure 3.1b) by Base engineers on 28 June 1995. Table 3.5 lists 84 compounds identified by library search. The primary separate phase petroleum constituents identified by the GCD are branched alkanes:

- (4.99% by area) 2,2 dimethylhexane
- (4.01% by area) octane
- (4.01% by area) nonane
- (3.79% by area) 2 methylheptane
- (2.91% by area) methylcyclohexane
- (2.87% by area) decane
- (2.57% by area) 2 methyloctane
- (2.57% by area) 1,1,3 trimethylcyclohexane

Aromatic compounds comprise 12.9% of the total separate phase hydrocarbons, distinguished by the following primary constituents:

- (1.67% by area) 1 ethyl 3 methylbenzene
- (1.67% by area) 1,3,5 trimethylbenzene
- (1.16% by area) propylbenzene
- (1.14% by area) 1,2,4 trimethylbenzene

Nineteen compound identities were confirmed by analyzing a GCD standard. This standard consists of a group of alkanes and aromatics distributed over a range of retention times

- (1.69 min) 2,3 dimethylpentane
- (1.94 min) trichloroethylene
- (1.94 min) heptane
- (2.78 min) 2 methylheptane
- (3.45 min) octane
- (3.59 min) tetrachloroethylene
- (4.17 min) 1,1,3 trimethylcyclohexane
- (4.71 min) ethylbenzene
- (4.81 min) 2 methyloctane
- (5.58 min) nonane
- (6.26 min) 3,6 dimethyloctane
- (6.93 min) 1,2,3 trimethylbenzene
- (7.40 min) 1,3,5 trimethylbenzene
- (7.58 min) decane
- (8.73 min) 2 methyldecane
- (9.36 min) undecane

TABLE 3.5 GCD IDENTIFICATION OF COMPOUNDS IN SEPARATE PHASE

| Retention Time, min | Area % | SAMPLE Compound | Match, % | Confirmed |
|---------------------|-------------------|----------------------------------|----------|-----------|
| 1.69 | 1.83 | 2,3-Dimethylpentane | 87 | Yes |
| 1.73 | 1.72 | 3-Methylhexane | 87 | |
| 1.83 | 4.99 | 2,2-Dimethylhexane | 78 | |
| 1.94 | 3.14 ^a | Trichloroethylene | Ion scan | Yes |
| 1.94 | 3.14 ^a | Heptane | 93 | Yes |
| 2.18 | 2.91 | Methylcyclohexane | 96 | Yes |
| 2.29 | 2.07 | 3,4-Dimethylhexane | 78 | |
| 2.39 | 0.52 | 1,2,4-Trimethylcyclopentane | 78 | |
| 2.51 | 3 | 2,3,4-Trimethylpentane | 90 | |
| 2.58 | 2.79 | 2,3,3-Trimethylpentane | 90 | |
| 2.67 | 1.41 | 2,3-Dimethylhexane | 78 | |
| 2.78 | 3.79 | 2-Methylheptane | 95 | |
| 2.91 | 2.39 | 3-Methylheptane | 95 | |
| 2.97 | 1.91 | cis-1,3-Dimethylcyclohexane | 95 | |
| 3.23 | 0.73 | cis-1-Ethyl-2-methylcyclopentane | 93 | |
| 3.34 | 0.76 | 1,3-Dimethyl-transcyclohexane | 94 | |
| 3.45 | 4.1 | Octane | 90 | |
| 3.5 | 0.43 | 1,3-Dimethyl-cis-cyclohexane | 95 | |
| 3.59 | 0.37 | Tetrachloroethylene | 99 | |
| 3.72 | 0.53 | 2,3,5-Trimethylhexane | 90 | |
| 3.89 | 0.38 | 2,4-Dimethylheptane | 91 | Yes |
| 4.04 | 1.48 | 2,6-Dimethylheptane | 94 | |
| 4.09 | 1.23 | Ethylcyclohexane | 90 | |
| 4.17 | 2.57 | 1,1,3-Trimethylcyclohexane | 50 | |
| 4.42 | 0.59 | 1-Nonene | 43 | |
| 4.47 | 0.58 | 1,3,5-Trimethylcyclohexane | 91 | |
| 4.62 | 1.15 | 2,3-Dimethylheptane | 86 | |
| 4.71 | 0.47 | Ethylbenzene | 91 | |
| 4.81 | 2.57 | 2-Methyloctane | 91 | |
| 4.89 | 0.43 | p-Xylene | 97 | |
| 4.97 | 2.46 | 3-Methyloctane | 87 | Yes |
| 5.24 | 1.68 | 1-Ethyl-3-methylcyclohexane | 81 | |
| 5.28 | 0.33 | 1-Ethyl-4-methyltranscyclohexane | 83 | |
| 5.58 | 4.01 | Nonane | 87 | |
| 5.65 | 0.41 | 1-Bromo-3-methylcyclohexane | 64 | |
| 5.88 | 0.83 | Bicyclo[3.3.1]nonane | 76 | |
| 6.04 | 0.45 | 1-Methylethylbenzene | 93 | |
| 6.08 | 0.47 | 2-Ethyl-1-decanol | 59 | |
| 6.13 | 0.55 | 1-Methylethylcyclohexane | 91 | |
| 6.26 | 1.43 | 3,6-Dimethyloctane | 90 | |
| 6.39 | 0.78 | 3-Ethyl-2-methylheptane | 72 | |

**TABLE 3.5 (Continued) GCD IDENTIFICATION OF COMPOUNDS IN
SEPARATE PHASE SAMPLE**

| Retention Time, min | Area % | Compound | Match, % | Confirmed |
|------------------------|--------|--|----------|-----------|
| 6.63 | 1.16 | Propylbenzene | 83 | |
| 6.8 | 1.67 | 1-Ethyl-3-methylbenzene | 93 | |
| 6.89 | 0.56 | 2-Methylnonane | 91 | |
| 6.93 | 0.82 | 1,2,3-Trimethylbenzene | 95 | Yes |
| 7 | 0.96 | 3-Methylnonane | 70 | |
| 7.14 | 0.67 | 1-Ethyl-2-methylbenzene | 94 | |
| 7.2 | 0.31 | 1-Methyl-3-propylcyclohexane | 72 | |
| 7.24 | 0.32 | 1-Methyl-4-(1-methylethyl)-cyclohexane | 45 | |
| 7.4 | 1.67 | 1,3,5-Trimethylbenzene | 94 | Yes |
| 7.58 | 2.87 | Decane | 97 | Yes |
| 7.94 | 1.14 | 1,2,4-Trimethylbenzene | 94 | |
| 7.99 | 1.21 | 4-Methyldecane | 94 | |
| 8.11 | 0.73 | Butylcyclohexane | 93 | |
| 8.19 | 0.69 | 3-Methyldecane | 70 | |
| 8.27 | 0.53 | 3-Methyldecane | 87 | |
| 8.49 | 0.85 | 1-Methyl-3-propylbenzene | 90 | |
| 8.53 | 0.46 | 1-Methyl-2-propylbenzene | 92 | |
| 8.61 | 0.52 | 5-Methyldecane | 70 | |
| 8.67 | 0.41 | 4-Methyldecane | 97 | |
| 8.73 | 0.75 | 2-Methyldecane | 93 | Yes |
| 8.84 | 0.47 | 3-Methyldecane | 97 | |
| 8.96 | 0.62 | 4-Ethyl-1,2-dimethylbenzene | 91 | |
| 9.07 | 0.75 | 1,2,3,4-Tetramethylbenzene | 83 | |
| 9.36 | 2.39 | Undecane | 96 | Yes |
| 9.47 | 0.28 | Decahydro-2-methylnaphthalene | 90 | |
| 9.6 | 0.34 | 1-Methyl-4-(1-methylethyl)-benzene | 91 | |
| 9.75 | 0.36 | Decahydro-2-methylnaphthalene | 90 | |
| 9.79 | 0.31 | 3,8-Dimethylundecane | 83 | |
| 9.9 | 0.34 | n-Amylcyclohexane | 90 | |
| 9.97 | 0.25 | Pentylcyclopentane | 38 | |
| 10.26 | 0.26 | 3,6-Dimethyldecane | 52 | |
| 10.33 | 0.29 | 4-Methylundecane | 58 | |
| 10.4 | 0.6 | 2-Methylundecane | 95 | |
| 10.52 | 0.28 | 3-Methylundecane | 78 | |
| 11.08 | 1.91 | Dodecane | 95 | Yes |
| 11.35 | 0.62 | 2,6-Dimethylundecane | 96 | |
| 12.38 | 0.28 | 4-Methyldodecane | 95 | |
| 12.52 | 0.41 | 2-Methyldodecane | 72 | |
| 12.77 | 0.42 | 4,6-Dimethyldodecane | 83 | |
| 13.3 | 0.37 | 2-Methylnaphthalene | 94 | |

TABLE 3.5 (Continued) GCD IDENTIFICATION OF COMPOUNDS IN SEPARATE PHASE SAMPLE

| Retention Time, min | Area % | Compound | Match, % | Confirmed |
|---------------------|--------|--------------------------|----------|-----------|
| 13.59 | 1.55 | Tridecane | 97 | Yes |
| 16.57 | 0.35 | 2,6,11-Trimethyldodecane | 86 | |
| 17.81 | 0.86 | Tetradecane | 91 | Yes |

^aHeptane and trichloroethylene coelute, TCE content is by ion scan.

These 19 compounds (plus toluene) were combined into a methylene chloride solution, with an individual constituent concentration of 10 mg/L. Once prepared, the pure standard was serially diluted to produce 0.1, 0.01, and 0.001 mg/L liquid standards.

3.4 Soil Gas Sampling

3.4.1 Overview of Soil Gas Sampling Technology

Soil gas sampling has proven to be a useful means of delineating the areal extent of gasoline [Deyo et al. (1993)], diesel fuel [Downey et al. (1991)], heating oil [Folkes et al. (1987)], and other light petroleum distillate spills beneath the ground surface. These immiscible hydrocarbons are lighter than water and so spread out over the water table. Evaporation is a preferential transport mechanism because the contaminants are volatile, giving rise to elevated concentrations of hydrocarbon vapors in the soil gas above the separate phase hydrocarbons. Thus, soil gas surveys may be used to delineate the separate phase source of petroleum contamination.

Soil gas sampling works best in dry, coarse grained soils with low organic carbon content [Marrin et al. (1988)]. Infiltrating water, perched water tables, low permeability lenses, barometric pressure fluctuations, lower soil temperatures, and biodegradation can all significantly reduce hydrocarbon vapor concentrations with increasing distance from the separate phase source. The infiltrating water, barometric pressure, and soil temperature effects are transient and can introduce seasonal or diurnal variations in gaseous contamination [Deyo et al. (1993), Van Vliet et al. (1993)], so that frequent sampling from a permanent soil gas monitoring point is needed for a quantitative measure of contamination. Aerobic biodegradation of hydrocarbon vapors consumes oxygen [Ostendorf and Kampbell (1991)] and generates carbon dioxide [Kerfoot et al. (1988)], while anaerobic degradation creates methane gas [Marrin (1991)]. The correlation of these constituents with an inert tracer gas is often used to assess the biodegradation potential of petroleum spills in the subsurface environment [Miller et al. (1991), Kittel et al. (1993)].

A suite of increasingly sophisticated technologies is available for the sampling and analysis of soil gas. Probes as simple as a 1.3 cm diameter stainless steel tube tipped with a loose carriage bolt [Kampbell et al. (1990)] or a drive point [Deyo et al. (1993)] have been deployed successfully in the field, as have more elaborate 2.0 cm diameter stainless steel systems

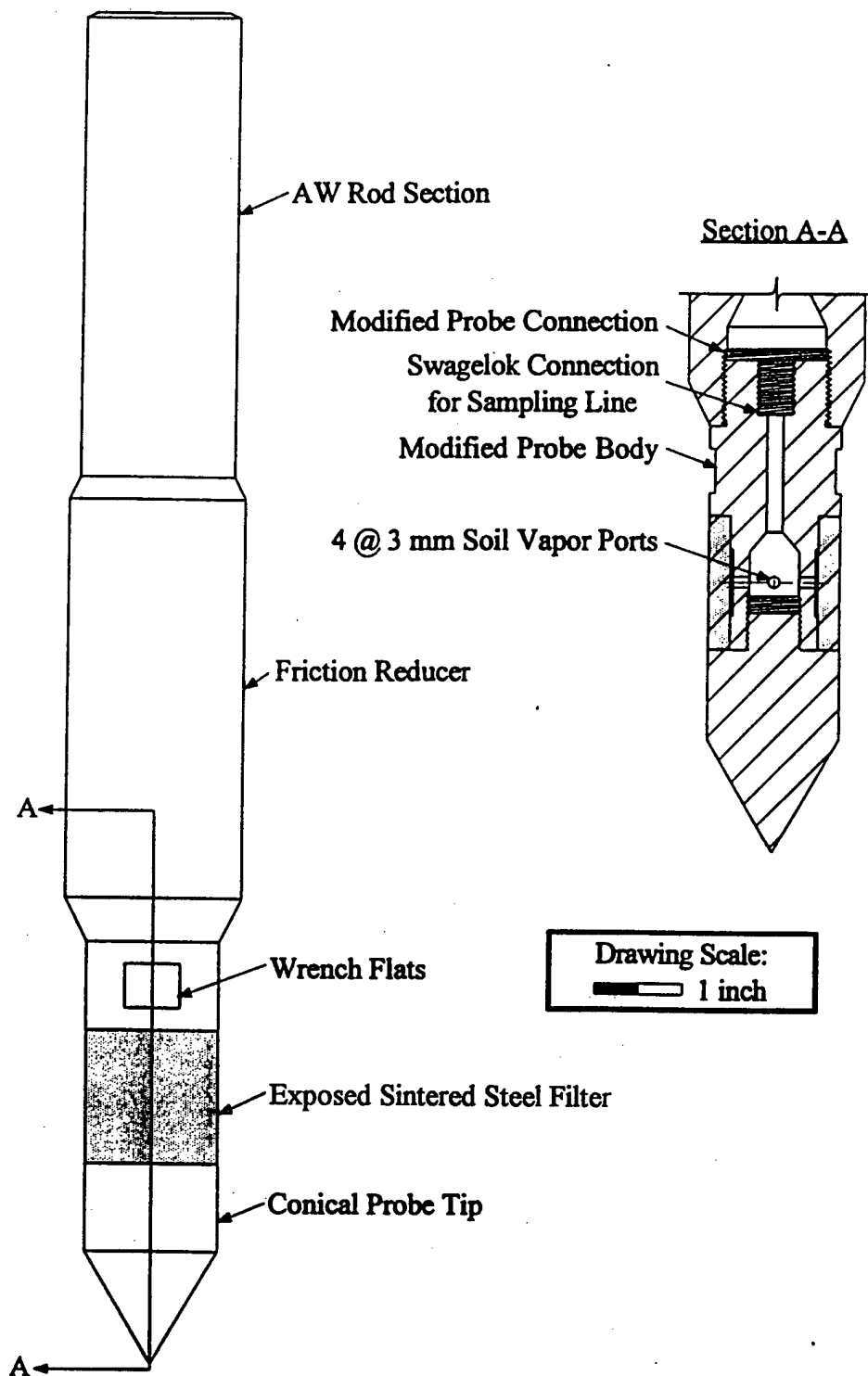


Figure 3.13 Stainless Steel Vapor Sampling Probe

with side ports [Kerfoot (1987)], or retractable shields [Christy and Spradlin (1992)]. The driving force may be a manual or handheld electric hammer [Kampbell et al. (1990), Kerfoot (1987)], truck mounted piston [Tillman and Leonard (1993)], or a drill rig mounted hammer [Ostendorf et al. (1995c)], depending on the type of soil and sampling depth. Shields or filter elements may be required for finer grained soils to prevent clogging of ports. Soil gas is pulled from the probes through stainless steel or flexible tubing to the ground surface by manual

[Kerfoot (1987)] or electric vacuum sampling pumps, where it can be trapped for subsequent laboratory analysis [Moyer et al. (1994)], subsampled by syringes [Kerfoot (1987)], or directly fed into field meters [Kampbell et al. (1990)]. In the latter regard, organic vapor analyzers with built in vacuum pumps and catalytic combustion chambers are used to measure total hydrocarbon vapor pressures, while potentiometric cells and infrared absorption sensors also see widespread use for the detection of oxygen and carbon dioxide content, respectively. Tedlar bag dilution may be needed for field meter readings of highly contaminated soil gas [Robbins et al. (1990)]. Petroleum distillates are blends of many hydrocarbon compounds with varying saturated vapor pressures, solubilities, and biodegradation potentials [Potter (1989)], and a catalytic combustion chamber does not differentiate constituents. Soil gas is consequently analyzed by direct injection or trap desorption into portable or mobile gas chromatographs to elucidate its hydrocarbon composition.

3.4.2 Vapor Probes

We used soil vapor probes to map the vertical distribution of soil gas constituents in the following boreholes:

- VP1-11 October 1995, 0.6 to 11.6 m depth, hydrocarbons, oxygen, and carbon dioxide
- VP2-11 October 1995, 0.61 to 7.9 m depth, oxygen
- VP3-13 October 1995, 0.3 to 6.1 m depth, hydrocarbons, oxygen, and carbon dioxide
- 12BC-21 August 1996, 10.1 to 11.3 m depth, hydrocarbons, oxygen, CO₂, and TCE
- 12BE-21 August 1996, 9.5 to 11.4 m depth, hydrocarbons, oxygen, CO₂, and TCE
- 12BH-21 August 1996, 9.3 to 11.0 m depth, hydrocarbons, oxygen, CO₂, and TCE
- 12BJ-21 August 1996, 9.3 to 11.0 m depth, hydrocarbons, oxygen, CO₂, and TCE
- 12BK-22 August 1996, 9.3 to 11.1 m depth, hydrocarbons, oxygen, CO₂, and TCE
- 12BM-22 August 1996, 9.3 to 11.1 m depth, hydrocarbons, oxygen, CO₂, and TCE
- 12BN-22 August 1996, 9.3 to 11.0 m depth, hydrocarbons, oxygen, CO₂, and TCE

Table 3.1 and Figure 3.1 locate the vapor probe boreholes.

Two different probes were designed, fabricated, and deployed by UMASS personnel on field trips in October 1995 and August 1996. Nearly all of the data were obtained with a 3.81 cm diameter stainless steel vapor sampling probe sketched in Figure 3.13, and used at other hydrocarbon spill sites [Ostendorf et al. (1995a)]. The probe is equipped with a 5.1 cm friction reducer and a sintered 40 μ m stainless steel filter element, flush mounted and exposed to the soil. The probe is driven through hollow stem augers into undisturbed soil by a 140 pound SPT rig mounted safety hammer with a 0.76 m drop height. The probe admits soil gas through four 3.18 mm diameter ports to a plenum connected to 1.6 mm ID nalgene tubing routed to the surface through the annulus of AW drill rods. The thin tubing minimizes purging requirements, and was coupled to the surface sampling system with stainless steel 6.4 mm Swagelok fittings. A generator (Honda EX1000) powered, Cole Parmer Model 7530-40 single head diaphragm vacuum pump equipped with a water trap, vacuum gauge, and Cole Parmer 0-5 L adjustable flow meter pulled gas to the ground surface at a rate of 2 L/min. We purged one L of soil gas from the

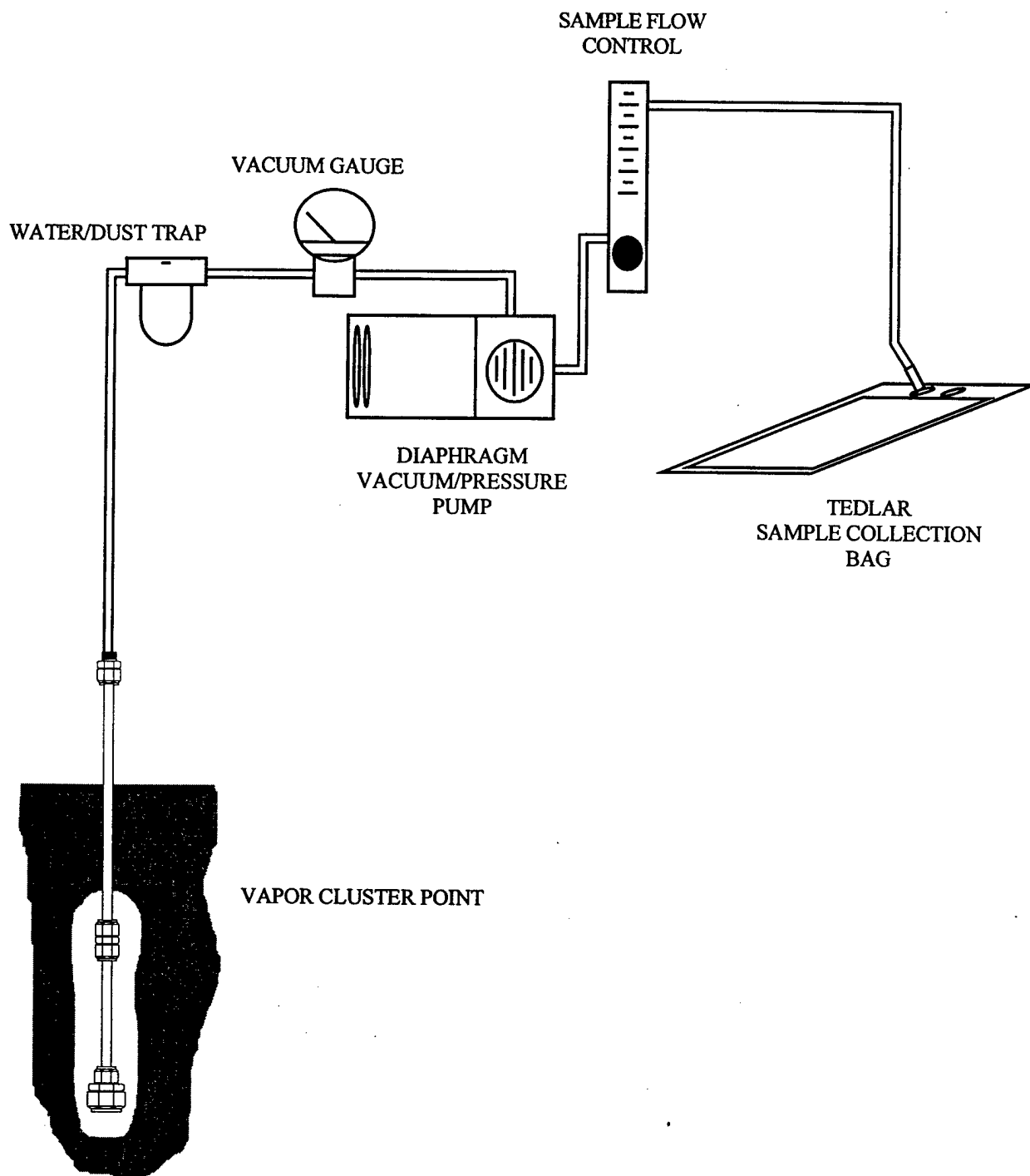


Figure 3.14 Soil Gas Sampling System

system before filling 2 L of sample into evacuated, nitrogen rinsed, 3 L Tedlar bags (SKC Company, Eight Four, PA). Figure 3.14 displays the soil gas sampling equipment, which is used for vapor probes and stainless steel tubing clusters.

Borehole VP2 was sampled with a GC Industries (Freeport, CA) model GC 33-200 potentiometric oxygen sensor mounted in the plenum of the stainless steel vapor probe sketched

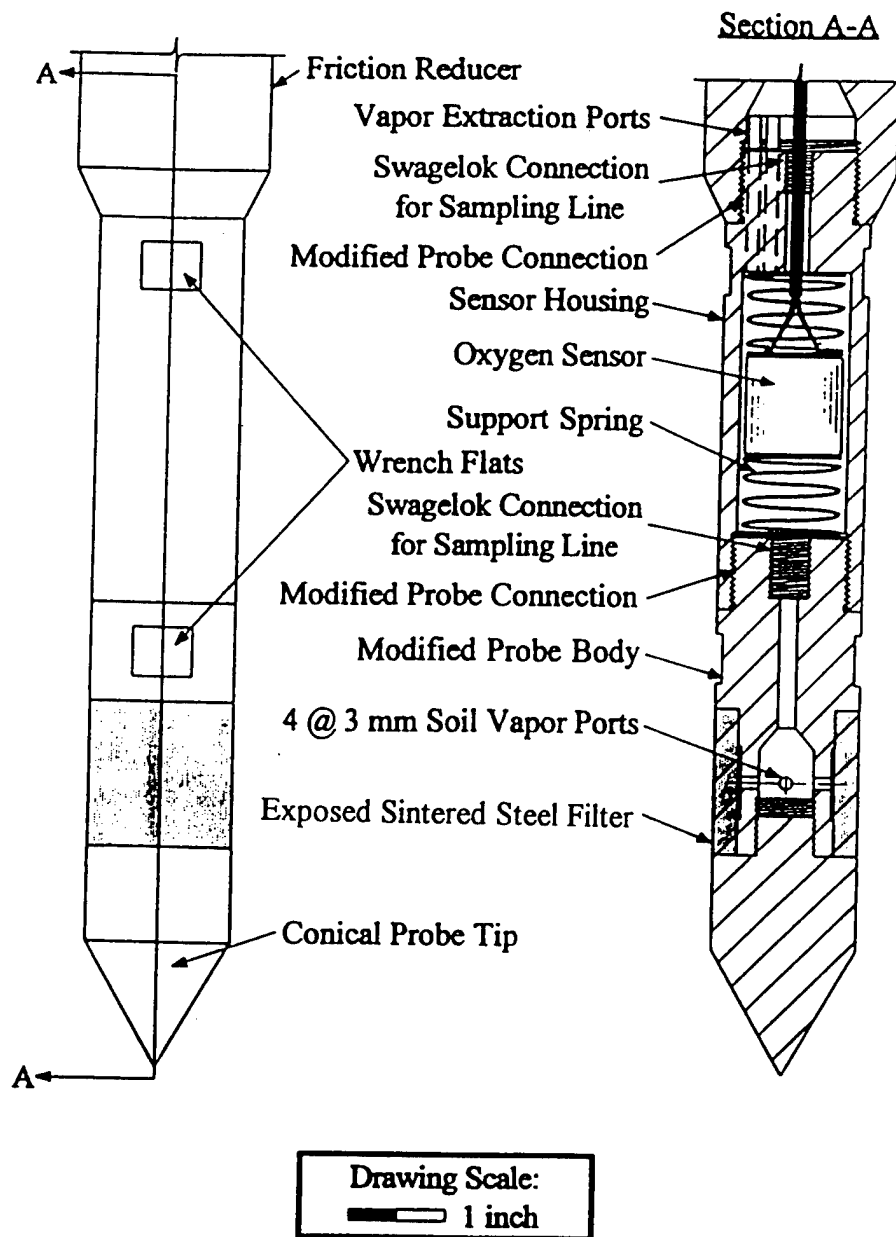


Figure 3.15 Downhole Soil Gas Oxygen Sensor in Stainless Steel Probe

in Figure 3.15. The sensor housing is isolated from hammer shocks by support springs, and sends a signal up a lead through the AW rod annulus. The lead is tied to nalgene tubing, which is itself connected to the vacuum pump used to draw soil gas into the plenum for downhole sensing. Since the analysis is downhole, no purging is needed. Figure 3.16 compares the downhole sensed oxygen in borehole VP2 with soil gas oxygen observed in Tedlar bag samples from borehole VP1 using a Bacharach model 302 oxygen meter. The data agree, with an average precision of 8% (as defined by Equation 3.2).

3.4.3 Stainless Steel Tubing Clusters and Near Surface Arrays

Soil gas constituents were also measured using a series of stainless steel tubing clusters placed in 26 boreholes throughout the study area. Table 3.1 and Figure 3.1 locate the clusters,

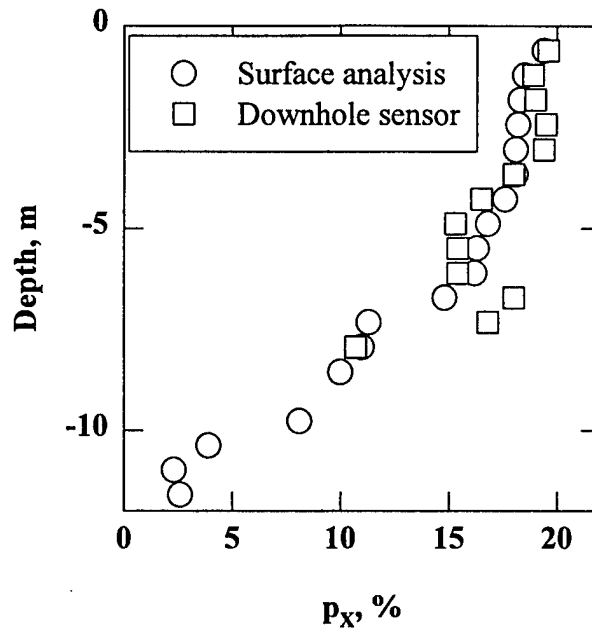


Figure 3.16 Downhole Sensed (Squares, VP2) and Surface Sensed (Circles, VP1) Soil Gas Oxygen Partial Pressure p_X

while Appendix II details their construction. The stainless steel soil gas points were installed at depths ranging from 0.9 to 11 meters below grade. Each soil gas point consisted of an inlet section, a riser, and a sampling connection, as shown in Figure 3.17. The inlet section, where soil gas enters the point, consisted of a Swagelok 1/4" to 1/2" union (Swagelok, Salon, OH) with a 1/2" diameter x 1/16" thick sintered stainless steel disk with 100 micron pores (Mott Metallurgical, Farmington, CT) installed in the 1/2" end of the union. The disk was secured by the 1/2" nut supplied with the union. The riser section consisted of the appropriate length of 1/4" OD x 3/16" ID stainless steel tubing attached to the 1/4" end of the union. Swagelok unions (1/4" x 1/4") were used in conjunction with the 1/4" OD stainless steel riser to install points at depths of over six feet. To form a sampling connection, 1/4" to 1/4" unions were used with one end attached to the riser and a Swagelok 1/4" female cap used to seal the top of the point when not in use. Single or multiple cluster points installed at the same location were completed by housing the surface sampling connections in 0.2 m diameter steel and cast iron road boxes (Boart-Longyear, Stone Mountain, GA) with removeable watertight caps fastened with three hexagonal bolts and set into a concrete pad.

We installed the soil gas cluster points by augering to the lowest sampling depth with 0.17 m OD hollow stem augers driven by a CME-75 drill rig. After reaching the appropriate depth, with the augers left in place, a 0.15 m sandpack layer (Morie Gravel) was placed and a cluster point was lowered down the hole. An additional 0.15 m of sand was then placed, followed by a 0.6 m thick bentonite pellet seal (Bentoseal). After all cluster points for a given hole were installed, the remainder of each hole was filled with a bentonite grout (Bentoseal). A tremie pipe was used to facilitate installation of the grout mix. Augers were periodically

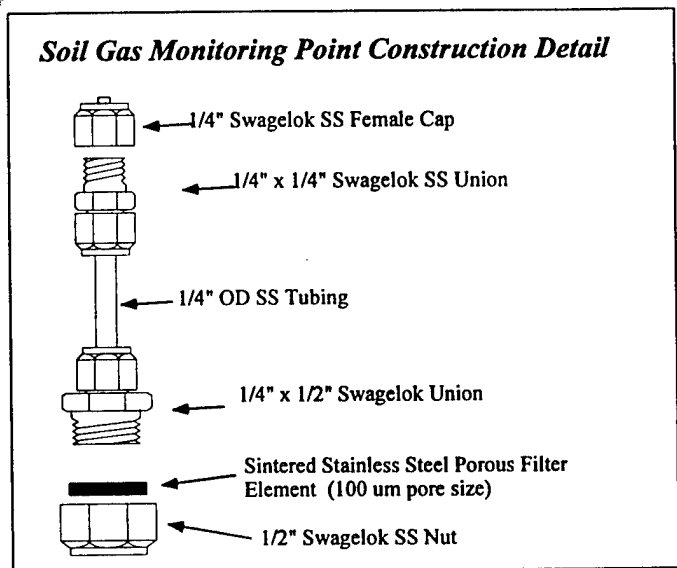
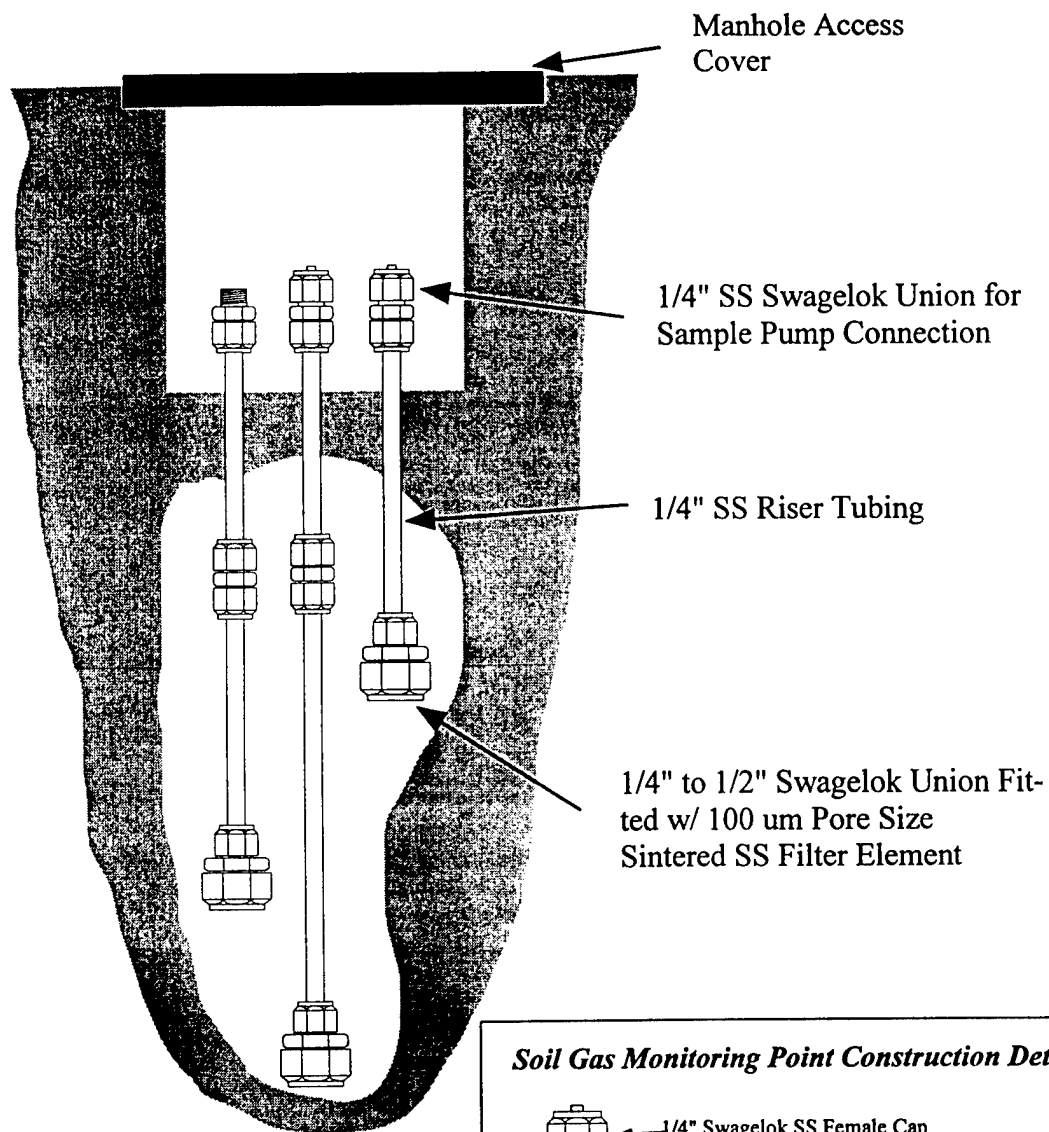


Figure 3.17 Stainless Steel Tubing Cluster Details

retracted so as to keep the hole open and to allow for proper placement of filter and sealing materials.

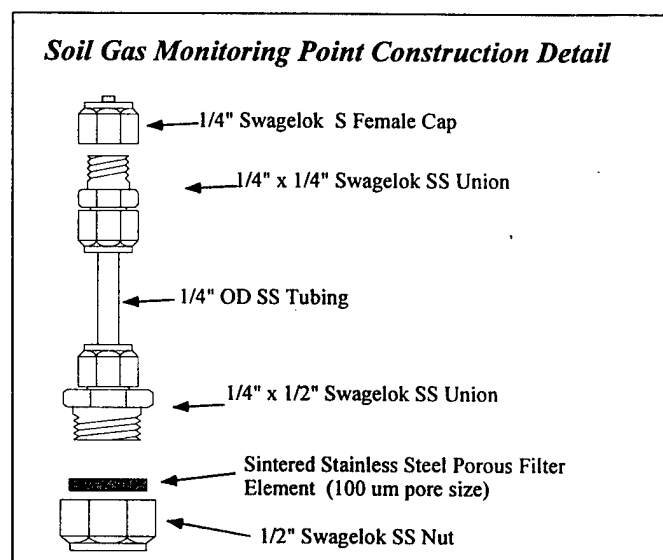
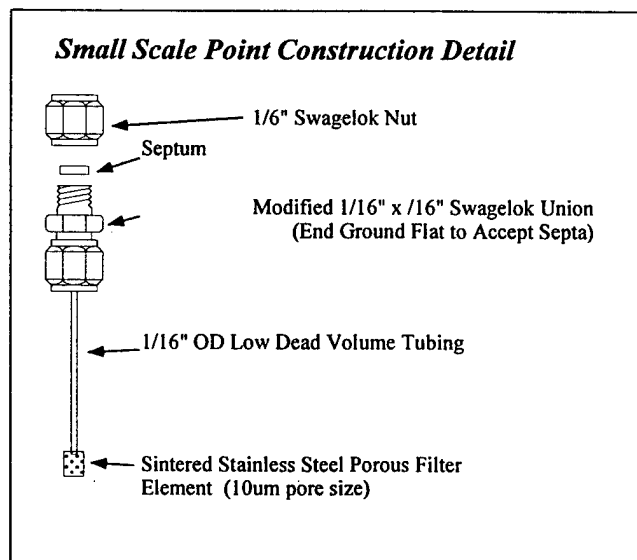
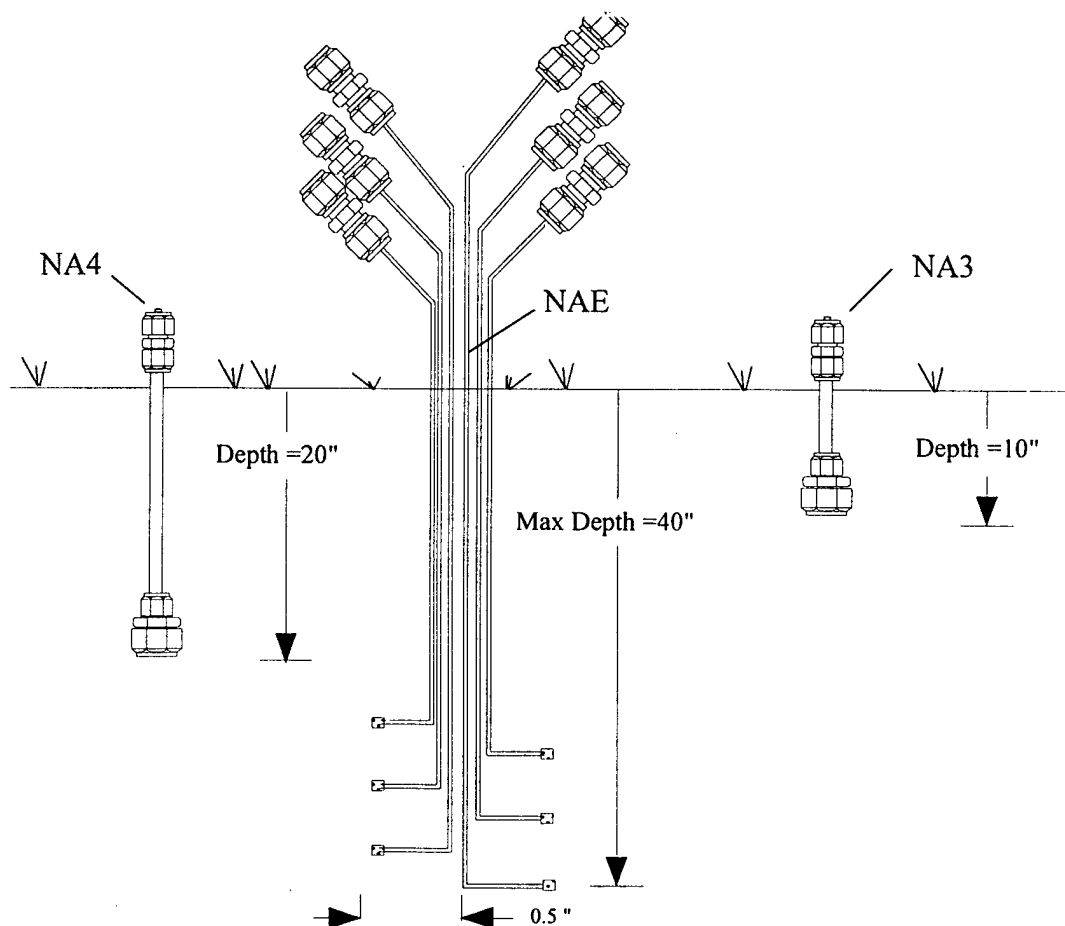


Figure 3.18 Near Surface Array Construction Details

Four stainless steel near surface arrays were constructed to resolve the vertical soil gas profile through the root zone of the site area at locations NAE and NAW, as shown in Figure 3.1. The small scale points (Figure 3.18) are constructed of the appropriate length of 1/16 inch diameter by 0.01 inch ID low dead volume tubing (Valco, Houston, TX) pressed into a 1/8 inch x 1/8 inch sintered stainless steel cup with a 10 mm pore size (Mott Metallurgical, Farmington,

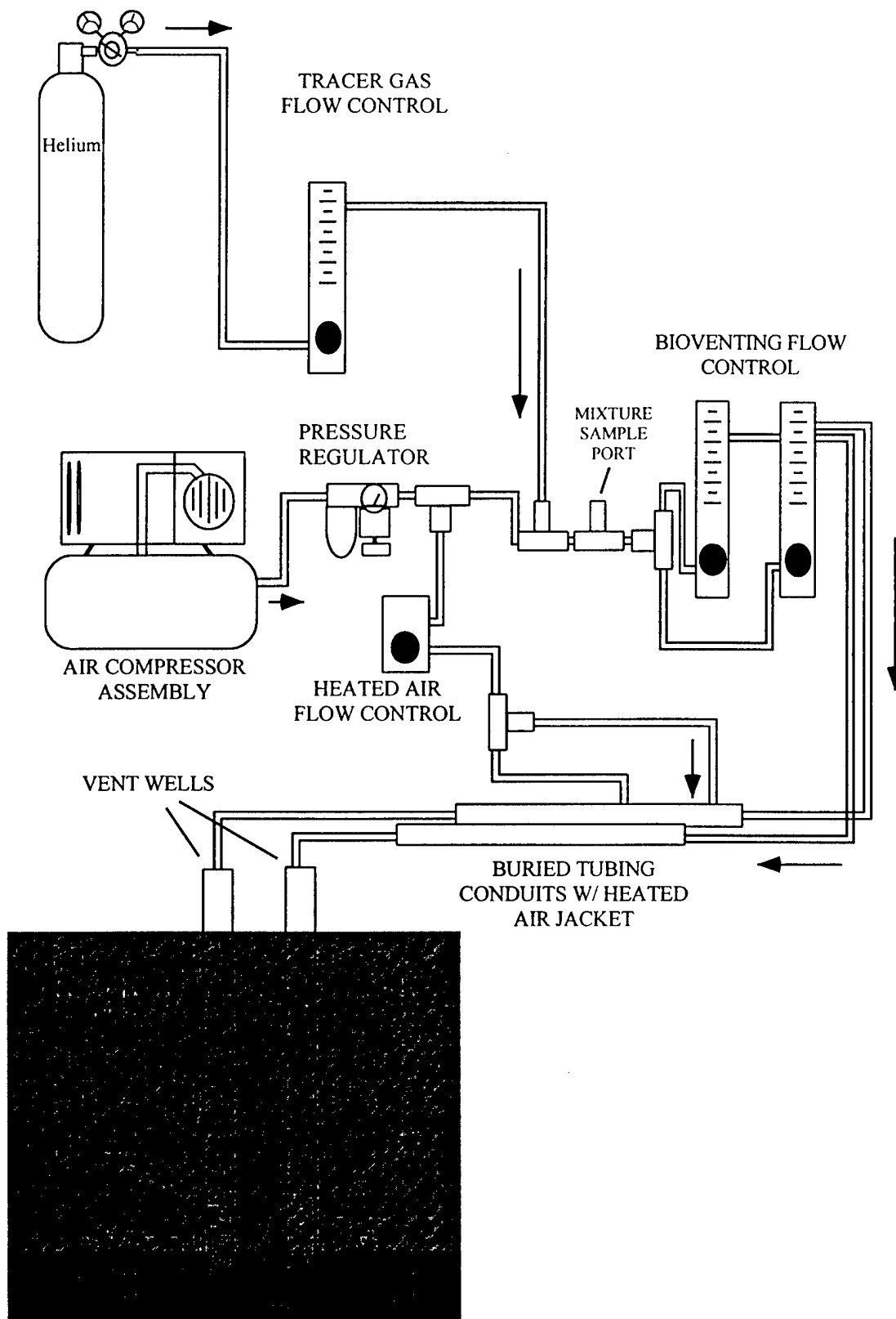


Figure 3.19 Soil Venting System

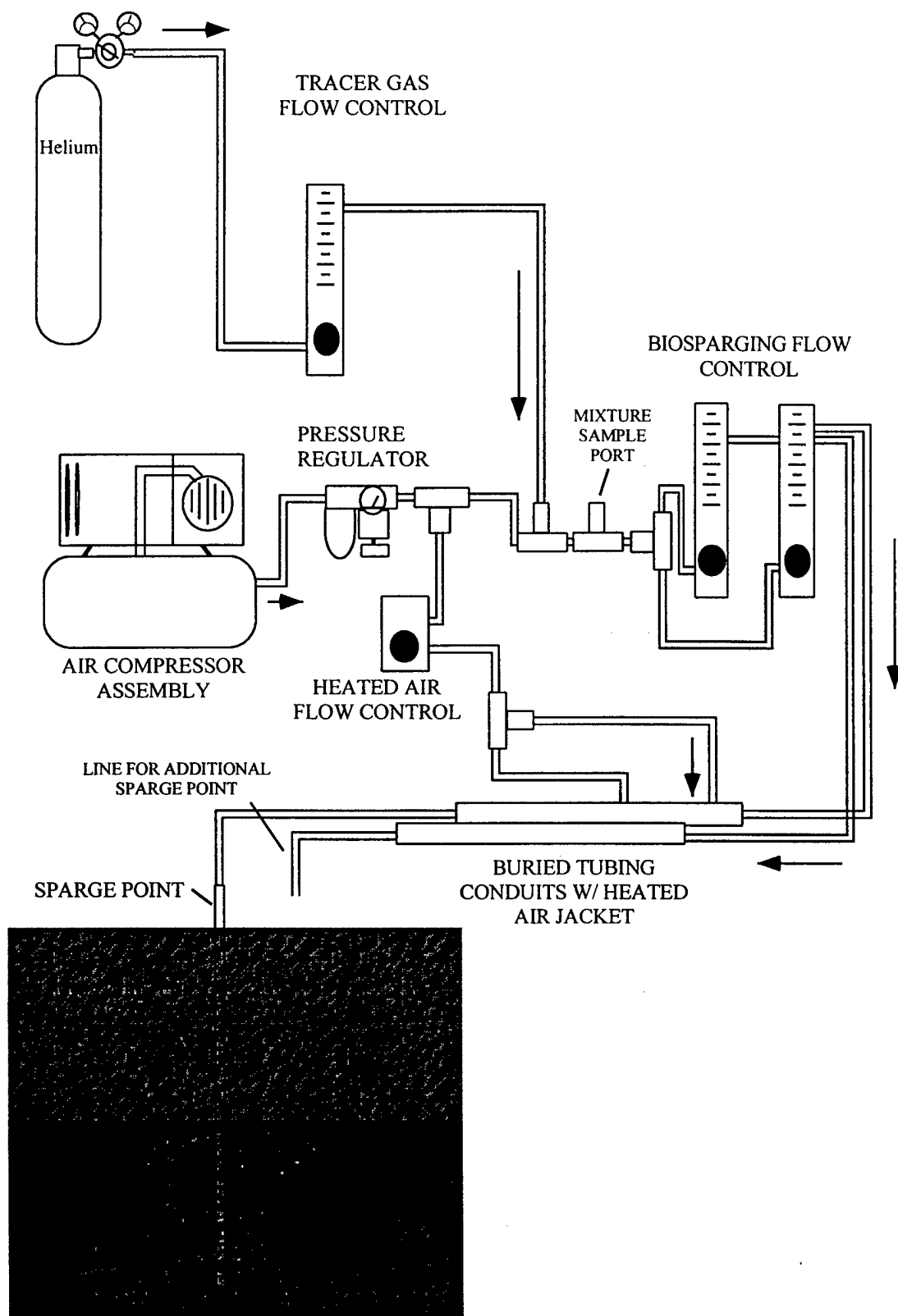


Figure 3.20 Air Sparging System

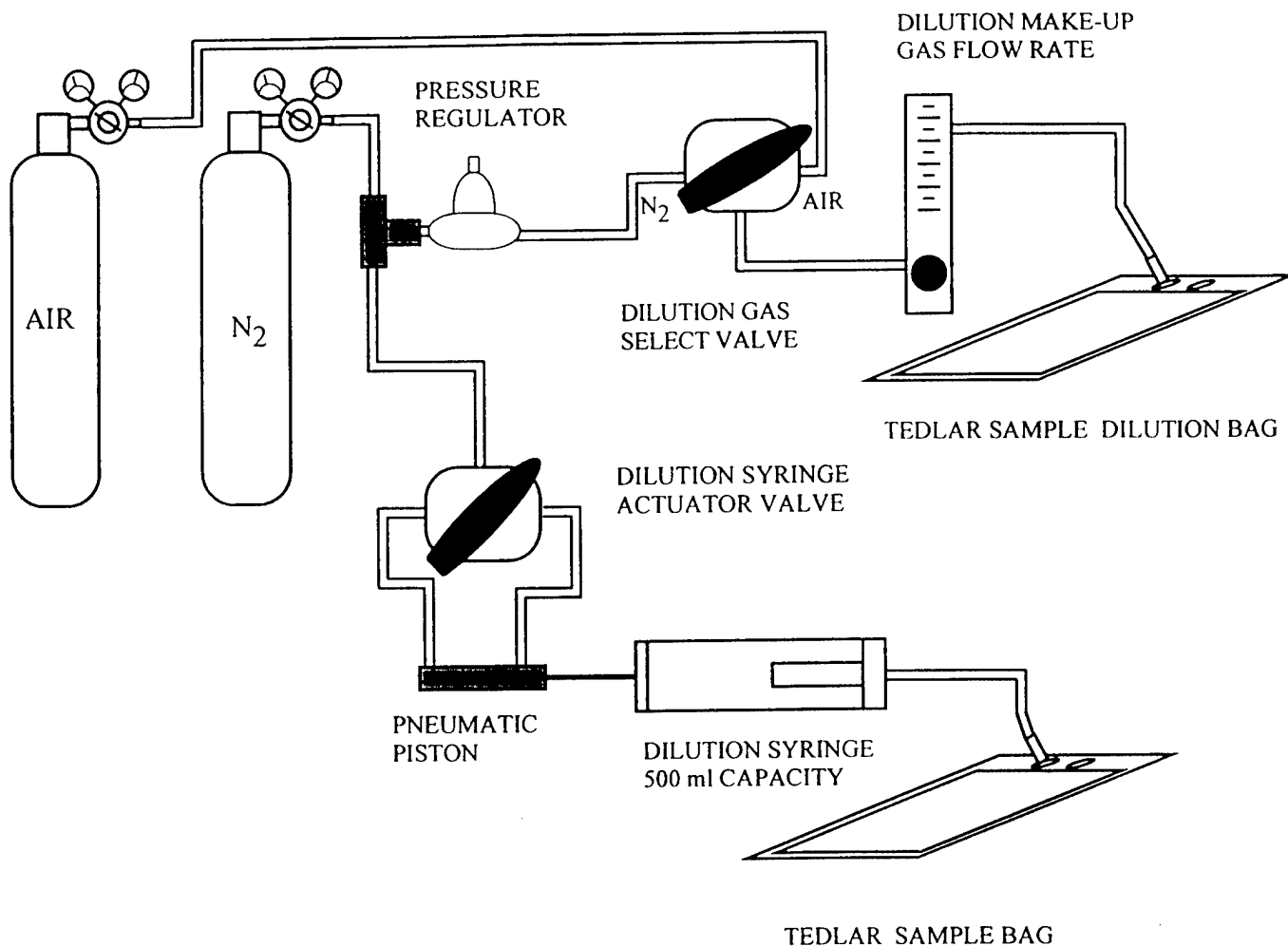


Figure 3.21 Tedlar Bag Dilution System

CT) A modified 1/16" to 1/16" stainless steel union (Swagelok, Solon, OH) was mounted at the other end which was fitted with a 5 mm GR-2 septa supplied by Supelco, Inc., Bellafonte, PA. We collected soil gas samples from each small scale near surface sample point using a Hamilton 250 μ L gastight syringe for on site analysis in a gas chromatograph. Prior to sample collection, 100 μ L of gas was purged from each point followed by a 250 μ L sample for direct injection and analysis by GC/ECD.

3.4.4 Soil Venting and Air Sparging Systems

Air was vented to the capillary fringe through two vent wells in boreholes VENT1 and VENT2. Figure 3.1 and Table 3.1 locate the vent wells, whose construction details are sketched in Appendix II. The two vent wells were installed using 0.2 m ID, 0.31 m OD hollow stem augers. Each well consisted of a 1.5 m section of 0.5 mm slotted, PVC well screen with a flush threaded cap at the bottom and 3-inch diameter flush thread PVC riser to the surface (Diedrich Drilling, Inc., LaPorte, IN). The vent wells were installed using six inches of sandpack (Morie

beneath the well point, 1.8 m of sandpack to 0.31 m above the well screen, a 3.1 m bentonite seal above this, and 3.1 m of grout above the bentonite. The remainder of the borehole was filled with native materials. At the surface, the wells were protected by 0.31 m diameter manholes (Boart-Longyear, Stone Mountain, GA). Each vent well was installed with a 1.5 meter screened interval based at 12.8 m below grade. The screens extended 0.76 m below the water table, and 0.76 m above the water table at the time of construction.

Air flow was supplied to the vent wells via 6.4 mm OD by 4.8 mm ID nylon tubing (Cole Parmer, Vernon Hills, IL) buried approximately 0.31 m below grade within a .02 m diameter PVC conduit surrounded by 0.013 m thick pipe insulation. Air lines entered the vent well manholes below grade through an access hole cut into the buried steel manhole skirts (Figure 3.19). The air lines were fitted to the 0.08 m diameter vent wells using 0.08 m to 0.05 m rubber couplings fitted with custom made 0.05 m to 1/4-inch NPT adapters. A total air injection rate Q of 28 L/min was conveyed to the vadose zone via the vent wells

$$Q = 4.67 \times 10^{-4} \frac{\text{m}^3}{\text{s}} \quad (\text{venting}) \quad (3.8)$$

A 1.2 x 1.2 x 1.2 m, wooden, fully insulated, pump shed was constructed and installed at the site to house the compressor, flow meters and valves. A Model 4H series 100 PSI, 3.5 CFM open flow, 230 VAC, oilless piston, compressor (Gast, Benton Harbor, MI) was used to provide air flow. Air from the pump flowed into a 0.2 m³ pancake type pressure ballast tank (Grainger, Lincolnshire IL) equipped with an automatic shutoff switch (Grainger). A combination line regulator and water trap (Grainger) was installed in the air line before reaching the manifold board. A 750/1000W ceramic heater (Toastermaster, Boonville, MO) was installed in the shed to maintain proper operating temperatures and to preheat ambient injection air.

Access to all controls and gauges was provided on a hinged manifold board. The manifold board was designed to be operated as two separate sections. Each section contained a tracer gas inlet port (Swagelok, Salon, OH) a mixture sampling port (Swagelok), a tee (Swagelok) into two flow meters with flow control valves, and two 0-15 PSI outlet pressure gauges (Cole Parmer, Vernon Hills, IL). Initially, the manifold board was set up to supply air to the two vent wells at flow rates of 14 L/min. in each well. The other two flow controlled outlets were used to blow warmed air into the 3/4" buried conduits containing the air supply lines to the vent wells in order to keep the air in the supply lines from condensing and freezing during winter operation.

Air was sparged into the subsurface below the water table through SPARGE1, a 2.0 cm diameter PVC injection pipe with a 0.5 mm slotted screen section 20 cm long. The screen was installed 1.2 m below the water table, set in a Morie sand pack with bentonite pellet and slurry seals, as delineated in Appendix II. Other well details are similar to VENT1 and VENT2.

A helium injection system was incorporated into both venting and sparging systems to facilitate tracer tests during system operation. Zero grade helium (Merriam Graves, Plattsburgh,

TABLE 3.6 SOIL VENTING AND AIR SPARGING TEST PROGRAM

| | Soil Venting | Air Sparging |
|-------------------|------------------------|------------------------|
| Start of air flow | 18 January 1996 | 9 August 1996 |
| End of air flow | 9 August 1996 | 5 September 1996 |
| Restart air flow | Not applicable | 24 October 1996 |
| Finish air flow | Not applicable | 19 December 1996 |
| Start tracer test | 7 February 1996 | 24 October 1996 |
| End tracer test | 7 March 1996 | 24 November 1996 |
| H_{INF} | 2,022 ppm ^a | 5,900 ppm ^a |
| Round 1 sampling | 13 February 1996 | 7 November 1996 |
| Round 2 sampling | 21 February 1996 | 20 November 1996 |

^aby volume.

NY) was fed into the injection air flow at a nominal flow rate of 100 mL/min through a Swagelok stainless steel union during four week periods in February and November 1996. Injection concentrations H_{INF} were measured in the discharge line with the results cited in Table 3.6, which also lists the venting and sparging periods, and the corresponding helium injection periods.

3.4.5 Soil Gas Sample Dilution and Portable Meters

There are several occasions when gas samples require dilution prior to or during analysis. One example is during hydrocarbon analysis. Often, when analyzing gas samples at petroleum contaminated sites, the samples contain high hydrocarbon concentrations and at the same time, low oxygen concentrations. One type of meter used for hydrocarbon analysis (the type used in the majority of field hydrocarbon analysis during this project) uses a catalytic combustion sensor which requires an oxygen level of at least 5% to provide an accurate hydrocarbon reading. Oxygen levels at petroleum contaminated sites near areas of heavy microbial activity can decrease to levels below 1%. Without the addition of oxygen, the hydrocarbon analysis meter will provide a reading that is too low due to the limited combustion that can take place in the sensor. To alleviate this problem, if a sample is analyzed and the oxygen concentration is below 5%, the sample is diluted by a factor of ten with zero grade air thus providing additional oxygen. The meter analysis is then reconducted and the hydrocarbon concentration is corrected for the tenfold dilution. Dilution can also be required when the concentration of a certain component of a soil gas mixture is present at concentrations that exceed the useable range of the instrument chosen for analysis. As an example, this can occur when carbon dioxide concentrations are in excess of 1% for one of the field meters to be used in this study (PMI-300) or when the total hydrocarbon concentrations are in excess of 10,000 ppm when using the Bacharach TLV meter.

Dilution of Tedlar bags for field analysis was conducted using the field dilution system (Figure 3.21). The field dilution system consists of a 500 mL gastight gas sampling syringe (Supelco, Bellafonte, PA), a pneumatic piston drive unit to actuate the syringe (Herbach and Rademan, Bristol, PA), a 5 L/min flow meter (Cole Parmer, Niles, IL), a 4 way valve to control the pneumatic piston (Swagelok, Salon, OH), a pressure regulator (Herbach and Rademan), and a

3-way air/nitrogen select valve (Swagelok), along with various hoses and fittings. Operation of the dilution apparatus is straightforward. The sample bag requiring dilution is attached to the 500 ml syringe intake/outlet line via a 1/8 inch to 3/16 inch union. The 4-way valve is turned causing the pneumatic piston to pull back the syringe plunger. Stops are installed so that a 200 ml sample is withdrawn from the sample bag. A clean bag is then attached to the dilution gas outlet to receive either air or nitrogen as the dilution gas depending on the type of dilution required. A volume of 1.8 liters (for a 10x dilution) of dilution gas is pumped into the additional bag. Once the bag has received 1.8 liters, it is then attached to the outlet tube on the syringe. The 200 ml sample collected from the original bag is then pumped into the dilution bag for a total volume of 2 liters. The 4-way valve and pneumatic piston are used to drive the syringe plunger as with the original sample withdrawal. The new bag is now ready to be analyzed but with a hydrocarbon or CO₂ concentration that is one tenth of the original value.

Oxygen, carbon dioxide, and total hydrocarbon soil gas concentrations in the field were measured using a series of handheld, battery operated instruments. Four meters were used for the bulk of the analyses:

- Total hydrocarbon pressure (p_G)-Bacharach TLV meter (Bacharach, Inc., Pittsburgh, PA)
- Oxygen pressure (p_X) Bacharach Model 302 Sniffer (Bacharach, Inc., Pittsburgh, PA)
- Carbon dioxide pressure (p_C) PMI-300 CO₂ analyzer (CEA Instruments, Inc., Emerson, NJ)

The Bacharach TLV Sniffer incorporates an "active" catalytic coated resistance element which oxidizes combustible gases as they enter the sensor. The heat produced by the oxidation process increases the resistance of the element proportional to the concentration of oxidizable material in the gas. An identical reference element without a catalytic coating is present along with the catalytic element in a wheatstone bridge configuration to compensate for ambient temperature changes and aging effects. A small internal bellows type sample pump draws sample gas into the sampling chamber at a flow rate of 2 L/min. The analog output meter operates with three scales: 0-100 ppm, 0-1,000 ppm, and 0-10,000 ppm. Calibration is performed by supplying hexane gas at a concentration of 500 PPM to the meter inlet and adjusting as per the owners manual operating instructions (Bacharach, 1990).

The Bacharach Model 302 Sniffer is a combination oxygen and combustible gas meter. Combustible gas concentrations are reported as percent of the lower explosive limit (% L.E.L) using the same sensing element as is in the Bacharach TLV unit. The oxygen portion of the unit consists of an electrochemical potentiometric cell capable of measuring O₂ concentrations in the range of 0-25%. The oxygen portion of the unit is calibrated to atmospheric concentrations (20.9%). Oxygen and combustible gas values are displayed on an LCD readout at the top of the unit. For this research, only the oxygen portion of the unit will be used. The TLV unit discussed above was used for combustible gas (hydrocarbon vapor) analysis.

The PMI-300 CO₂ meter is capable of measuring CO₂ concentrations in gas samples with a range of 0-100%. The method of detection is infrared absorbence. The functional portion of the unit consists of a glass cell through which the sample is pumped incorporating an infrared source, filter, and detector unit. The concentration of carbon dioxide in the cell contents is

proportional to the amount of infrared light absorbed. This signal is then conditioned, compared with a reference cell, and displayed on a 4 digit front mounted LCD readout. Controls for zero and full span are provided on the front. The unit is calibrated with a 99.8% CO₂ calibration gas (Scott Specialty Gas, Plumsteadville, PA). An adjustable flow rate sample pump draws the sample into the infrared absorbance cell.

3.5 Gas Chromatographic Analysis of Soil Gas Samples

Two Hewlett Packard Model 5890 laboratory gas chromatographs complete with PC-based data acquisition systems were brought to the field site for soil gas analysis. One gas chromatograph was equipped with two detectors: an electron capture detector (ECD), and a thermal conductivity detector (TCD), while the other had a flame ionization detector (FID). We used the FID to measure trichloroethylene in the tubing clusters and vapor probes, while the more sensitive ECD was reserved for near surface area samples with lower concentrations. Helium tracers were measured with the TCD. We describe the chromatography below.

3.5.1 Flame Ionization Detector

We withdrew a 250 μ L sample from the Tedlar bag using a Hamilton Gastight 250 μ L syringe equipped with a 26 gauge, bevelled tip needle. The FID gc was run with the following settings

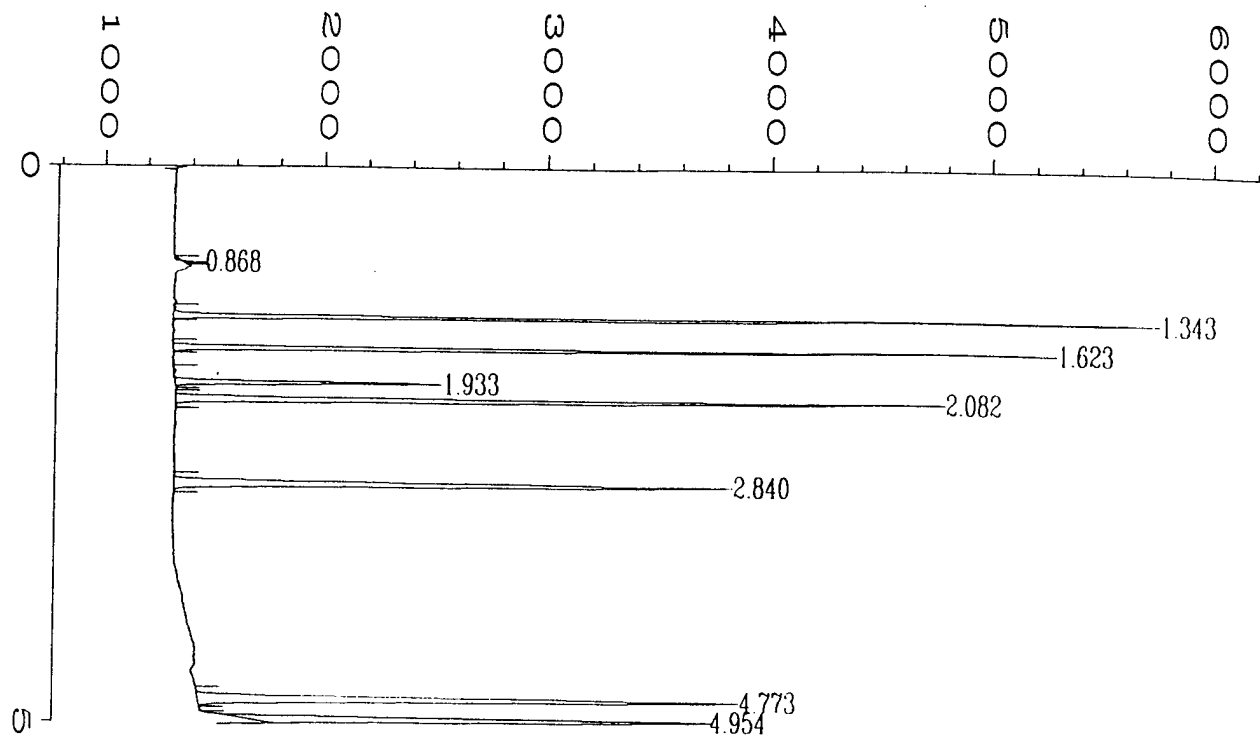
- Injector-20 to 1 split ratio, 250°K temperature, 2 mL/min zero grade N₂ carrier gas
- Capillary column-HP5 0.32mm diameter, 30 m length, 25 μ m film thickness (crosslinked 5% PH ME siloxane)
- Oven temperature-35°C for 3 min, 10°C/min to 70°C
- Detector-Temperature of 300°C, makeup gas flow rate of 20 mL/min

The data were captured with Hewlett Packard ChemStation software on a computerized data acquisition system.

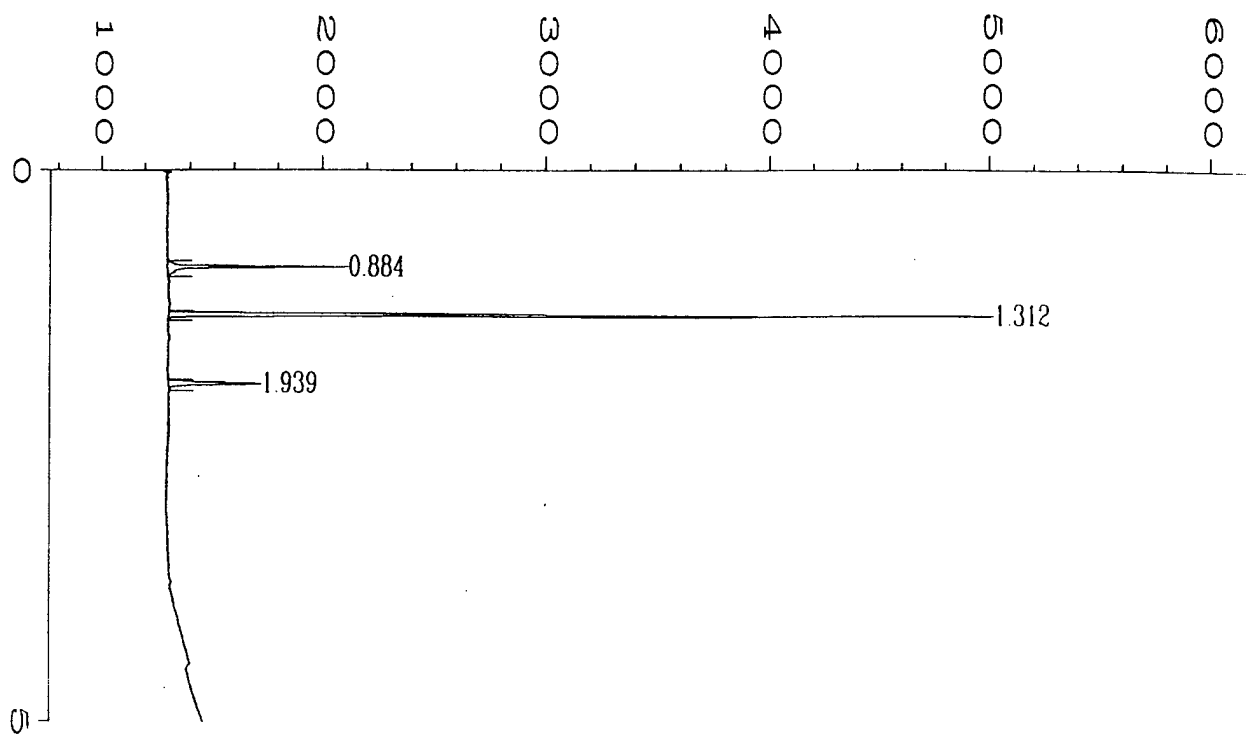
A synthetic gas standard (Scott Specialty Gases, South Plainfield, NJ) was used to calibrate the FID. The standard is comprised of a blend of 10 ppm partial pressures of seven compounds in nitrogen:

- hexane (1.343 minute retention time)
- benzene (1.623 minute retention time)
- trichloroethylene (1.933 minute retention time)
- heptane (2.082 minute retention time)
- toluene (2.840 minute retention time)
- ethylbenzene (4.773 minute retention time)
- m xylene (4.954 minute retention time)

Figure 3.22 displays typical chromatograms for the standard, and a soil gas sample.



Standard Chromatogram



Sample Chromatogram

Figure 3.22 Typical FID Chromatograms for Soil Gas

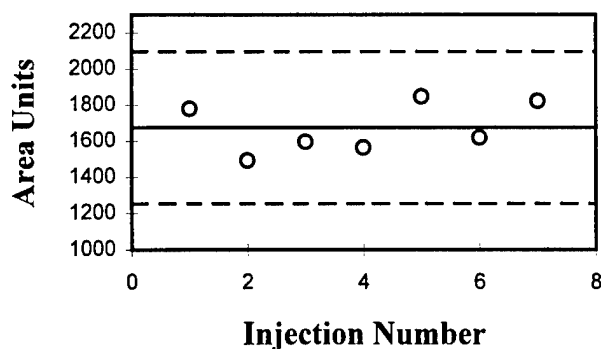


Figure 3.23 Method Detection Limit Study for TCE by FID

We ran a method detection limit (MDL) study by injecting seven replicate 10 ppm TCE soil gas samples into the gas chromatograph, with the results shown in Figure 3.23. Equations 3.5 and 3.6 are used to compute the MDL for trichloroethylene by FID analysis:

$$p_{YMDL} = 2.6\text{ppm} \quad (\text{FID}) \quad (3.9)$$

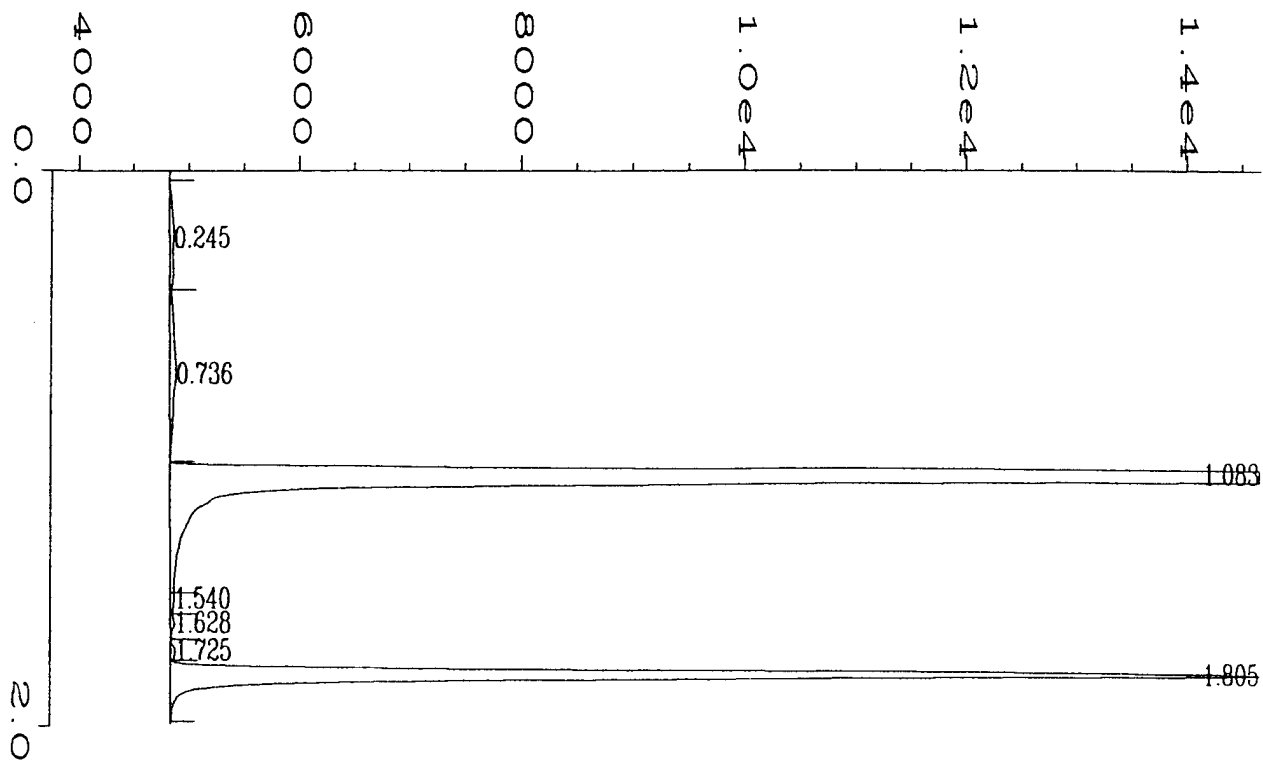
This precision is sufficient for observations in the tubing clusters and vapor probes. Concentrations diminish near the surface due to the atmospheric boundary condition however, so that a more sensitive detector is needed for the near surface array samples. This is provided by the ECD.

3.5.2 Electron Capture Detector

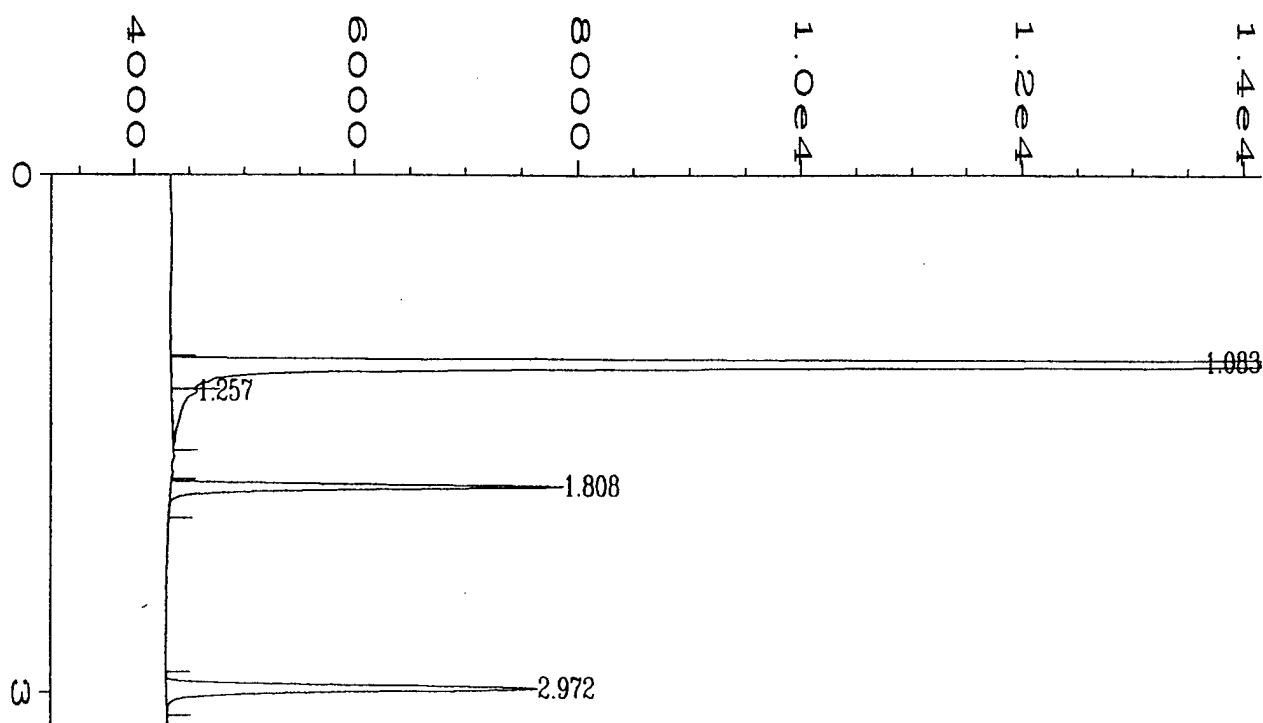
A 250 μL soil gas sample is injected into the gas chromatograph with the ECD, maintained at the following settings:

- Injector-20 to 1 split ratio, 200°C temperature, 2 mL/min zero grade N_2 carrier gas
- Capillary column-HP1 0.25mm diameter, 30 m length, 25 μm film thickness (crosslinked 1% PH ME siloxane)
- Oven temperature-35°C for 3 min, 10°C/min to 70°C
- Detector-Temperature of 250°C, makeup gas flow rate of 20 mL/min

The data were captured with Hewlett Packard ChemStation software on a computerized data acquisition system. A 100 ppb TCE standard was prepared by serial dilution of the FID standard in Tedlar bags. Figure 3.24 displays standard and sample chromatograms generated by the ECD.



Standard Chromatogram



Sample Chromatogram

Figure 3.24 Typical ECD Chromatograms for Soil Gas

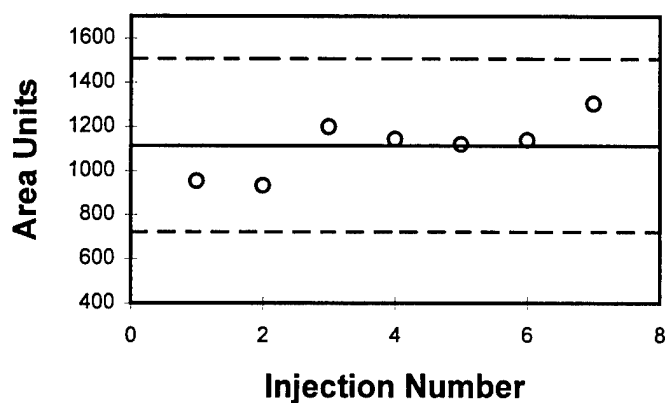


Figure 3.25 Method Detection Limit Study for TCE by ECD

TCE elutes at a retention time of 1.805 minutes. Figure 3.25 displays a method detection limit study for trichloroethylene vapors by ECD methodology. Seven replicate 1 ppm injections were run through the chromatograph, yielding an MDL of

$$P_{YMDL} = 3\text{ppb} \quad (\text{ECD}) \quad (3.10)$$

The highly precise MDL is suitable for near surface array analysis, which features TCE pressures ranging from 1 to 1,000 ppb.

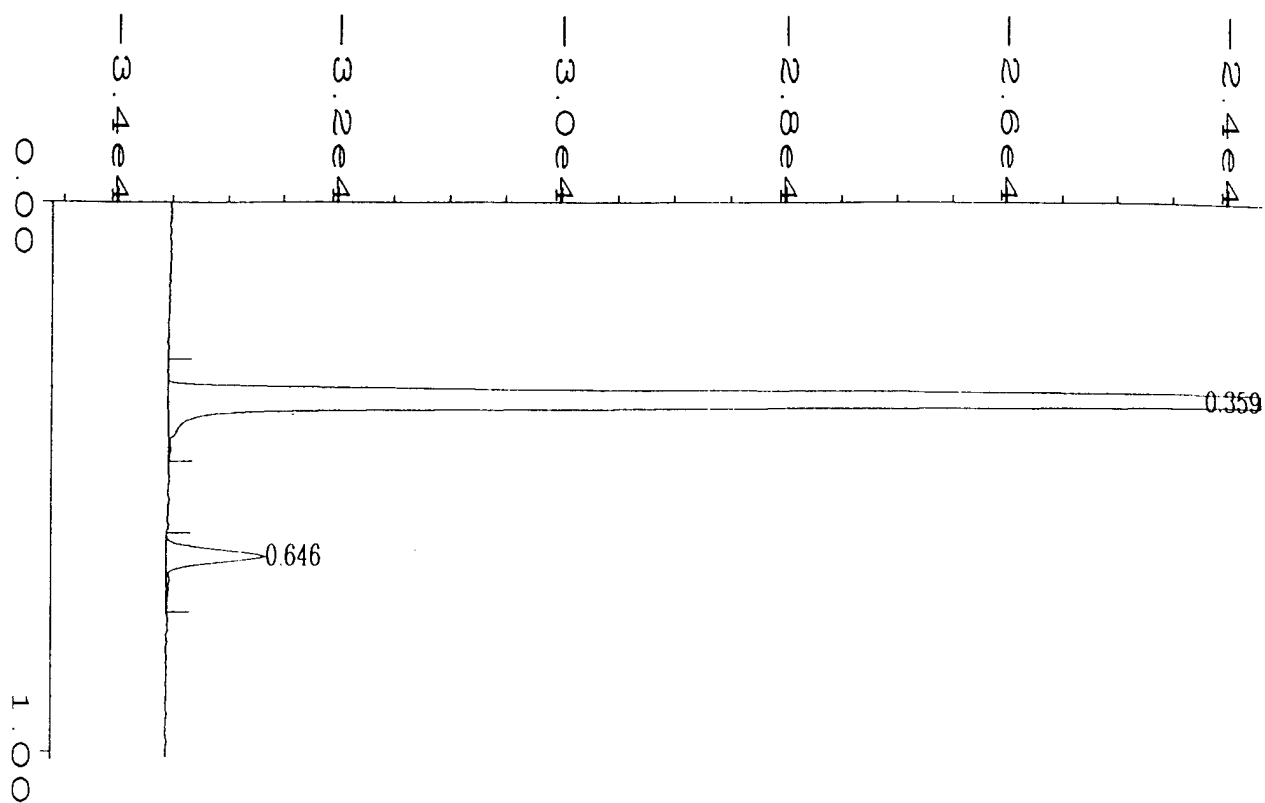
3.5.3 Thermal Conductivity Detector

Helium was sensed by a Hewlett Packard 5890 gas chromatograph equipped with a packed column and a thermal conductivity detector in accordance with the following program:

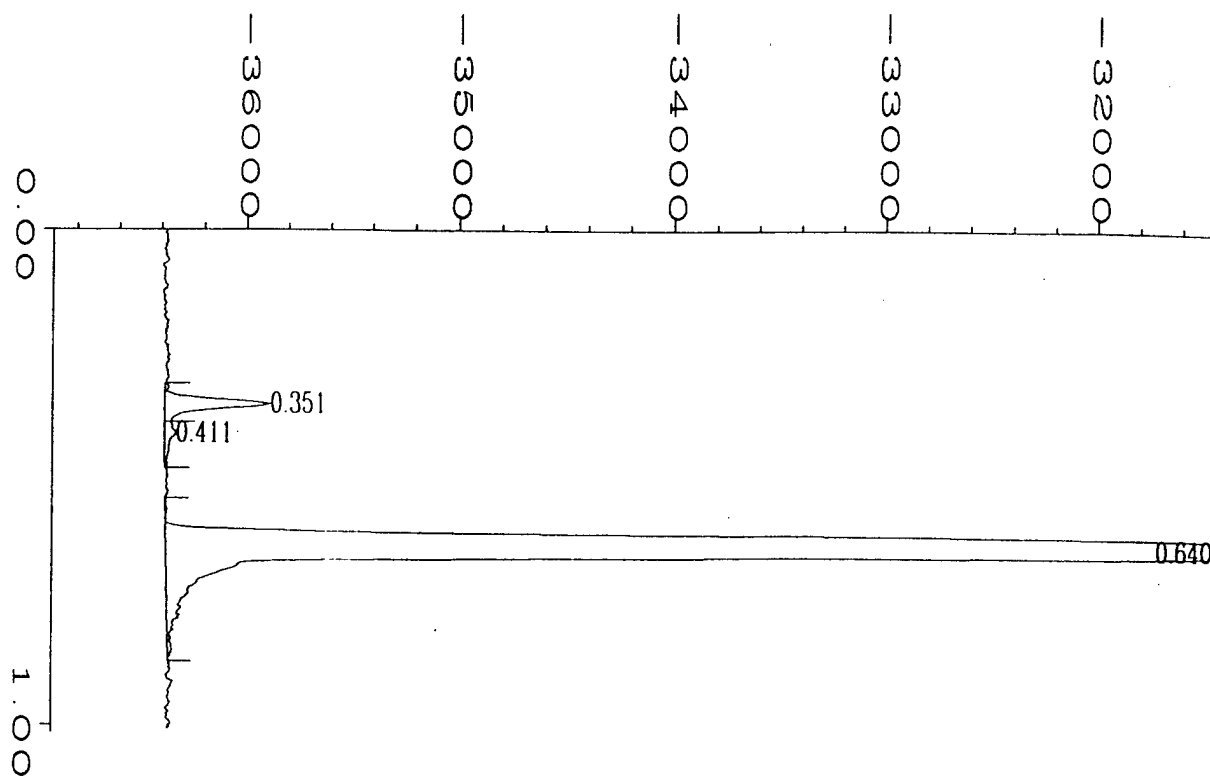
- Injector-splitless, 200°K temperature, 25 mL/min zero grade N₂ carrier gas
- Packed column-HP5 31 mm OD, 2 m length, 60/80 mesh molecular sieve
- Oven temperature-Isothermal at 50°C
- Detector-Temperature of 150°C

Helium standards were prepared by serial dilution of Tedlar bag samples, using successive 10 mL injections of pure helium (Merriam Graves, Plattsburgh, NY). Figure 3.26 shows typical standard and sample chromatograms for helium, which elutes at 0.359 minutes. We ran a method detection limit study for helium, as shown in Figure 3.27. The resulting MDL is

$$P_{HMDL} = 23\text{ppm} \quad (\text{TCD}) \quad (3.10)$$



Standard Chromatogram



Sample Chromatogram

Figure 3.26 Typical TCD Chromatograms for Soil Gas

3.6 Surface Isolation Flux Chamber

When conducting mass balance calculations on contaminant mass and monitoring emissions for regulatory reasons, it is often necessary to measure the efflux of contaminants from the ground surface to the atmosphere. There are several effective tools for measuring soil gas flux at the ground surface for the determination of contaminant impacts on ambient air. Surface flux measurements can also monitor the effectiveness of remedial actions such as containment barriers. Existing flux measurement equipment includes: the emissions isolation flux chamber, vent sampling, concentration profiles and transect methods. Transect and concentration profile methods require much instrumentation, are labor and time intensive, and are affected by varying site conditions such as temperature. Vent sampling is relatively simple but may not provide values representative of the area [Batterman et al. (1992)]. For these reasons, the flux chamber method is preferred for characterizing soil gas. However, there are still some disadvantages to isolation flux chamber use. Much equipment is required, including a compressed air supply, power, and flow balancing equipment. In addition the flux is only measured over a relatively small area, typically 0.1-0.3 m³ and over a relatively short and possibly non representative time period. Inherent heterogeneities at most sites require that to properly characterize a site, many points must be sampled, ideally simultaneously.

Batterman et al. (1992) describe an inexpensive, simple to install, and easy to analyze surface flux sampling system. The sampler consists of three major components: an inverted, open ended canister, an activated carbon layer installed at the top of the canister, and an absorbent badge. The carbon produces a gradient which simulates the vapors being swept away at the ground surface. The sampler is installed by pushing it a short way into the ground surface. After a predetermined period of time the canister is then retrieved. The absorbent badge is removed and compounds are extracted. Another stationary passive sampler method is described by Gomes et al. (1994). The PETREX method is a passive soil gas measurement technique combining stationary activated carbon coated filaments with high resolution GC/MS analysis thus making it capable of detecting and identifying over 9,000 VOC's and SVOC's. Detection limits for this method are generally in the ug/m³ range.

We designed and built a surface isolation flux chamber to measure emissions from the site area. Figure 3.27 displays the device, which is a modification of an Environmental Protection Agency design [Dupont (1987)], comprised of a stainless steel cylinder 18 cm high, with a 41 cm internal diameter. We welded a 51 cm outer diameter aluminum flange to the top of the cylinder to receive a Gore tex gasket and an acrylic dome. Five stainless steel ports are provided through the base of the chamber:

- temperature access port
- pressure gage port
- sweep gas inlet port
- sweep gas outlet port
- reserve port

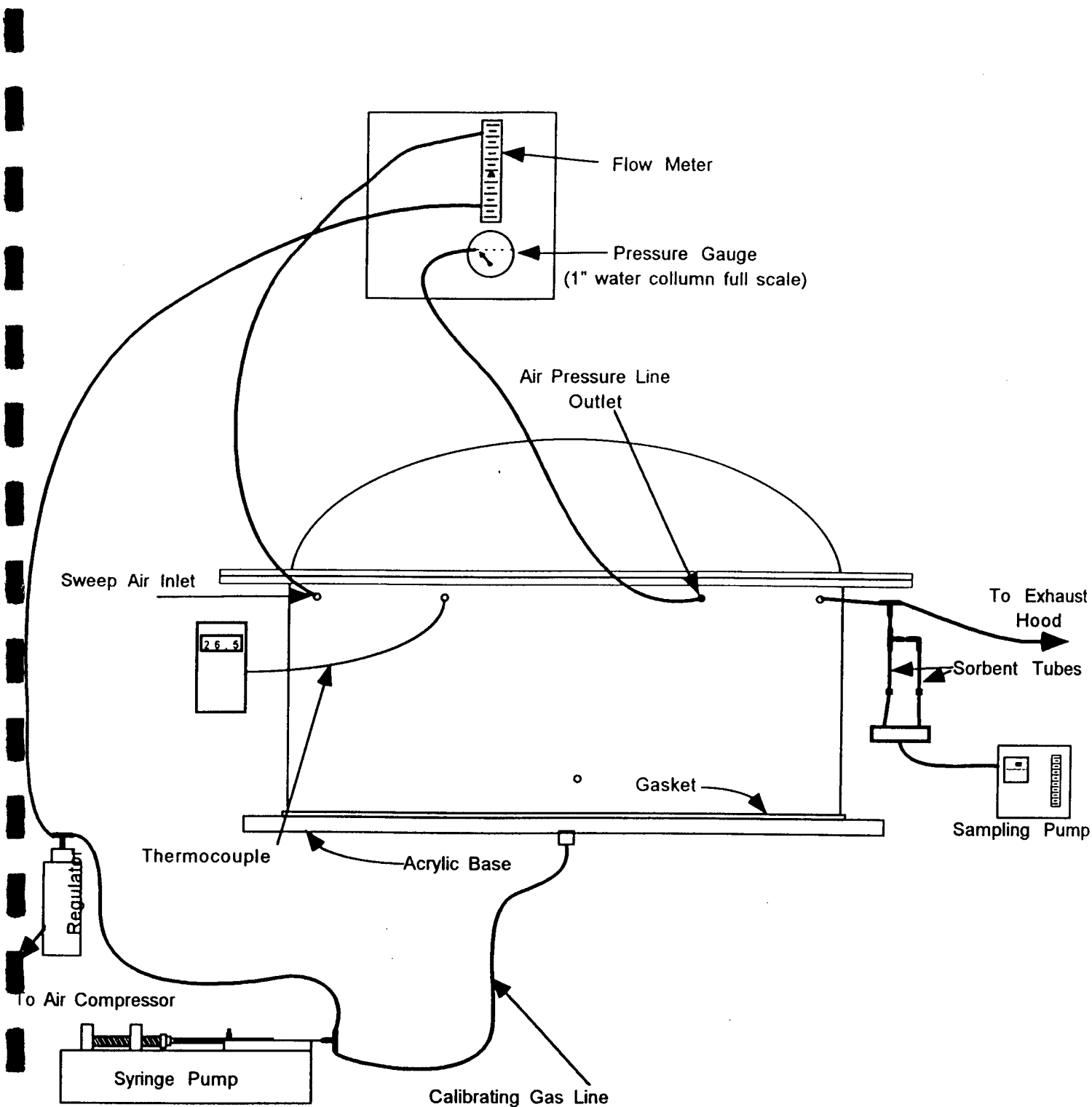


Figure 3.27 Surface Isolation Flux Chamber

Temperature was monitored with K type thermocouples (Omega, Stamford, CT), while magnehelic pressure gages were used to measure gas pressure. The chamber headspace was swept with regulated, metered (Aalborg Instruments and Controls, Monsey, NY), zero grade nitrogen gas (Merriam Graves, Plattsburgh, NY). Fine control was exerted by SKC 224

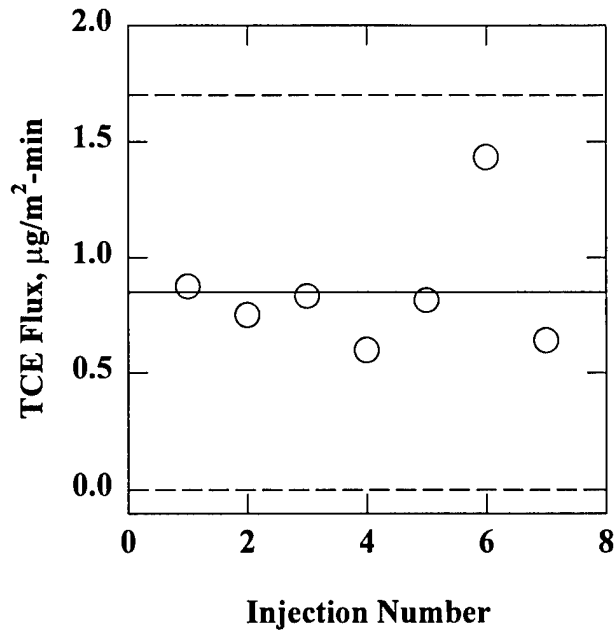


Figure 3.28 Method Detection Limit Study for Trichloroethylene Flux

sampling pumps (Eighty Four, PA) on the inlet and exhaust sample lines, which were of 6.3 mm diameter, Teflon construction with stainless steel Swagelok coupling. The exhaust sample line was equipped with a sampling port, for syringe withdrawal and gas chromatographic injection. A Hewlett Packard 5890 gas chromatograph with ECD was used to analyze the tetrachloroethylene concentrations, using the protocol stated in Section 3.5.2. Tehrany et al. (1996) use chemostatic analysis to relate the observed headspace concentration Y_{HEAD} to the flux J_{YO} emitted to the atmosphere

$$J_{\text{YO}} = \frac{(Q_{\text{SWEEP}} + w_{\text{O}}A_{\text{HEAD}})Y_{\text{HEAD}}}{A_{\text{HEAD}}} \quad (3.12)$$

with sweep flow Q_{SWEEP} and headspace area A_{HEAD} .

We conducted a method detection limit study for trichloroethylene flux in the laboratory by replicate injections of a 5.5 ppb standard, with the results summarized in Figure 3.28. The emissions protocol yielded a flux MDL of

$$J_{\text{YMDL}} = 0.87 \frac{\mu\text{g}}{\text{m}^2 - \text{min}} \quad (\text{ECD}) \quad (3.13)$$

4 MATHEMATICAL ANALYSIS

4.1 Soil Temperature

Seasonally varying surface temperature also imparts an annual frequency ω to the soil temperature τ , which is governed by a thermal diffusion equation [Carslaw and Jaeger (1973)]

$$\frac{\partial \tau}{\partial t} - D_T \frac{\partial^2 \tau}{\partial z^2} = 0 \quad (4.1a)$$

$$\tau = \tau_{\infty} \quad (z = -\infty) \quad (4.1b)$$

$$\tau = \tau_M \sin(\omega t + \phi) \quad (z = 0) \quad (4.1c)$$

with time t , elevation z above the ground surface, phase shift ϕ , thermal diffusivity D_T , mean temperature τ_{∞} , and seasonal amplitude τ_M .

A separation of variables technique is adopted [Rainville and Bedient (1969)] in view of the periodicity of the boundary condition 4.1c, leading to the following solution

$$\tau = \tau_{\infty} + \tau_M \exp\left(z \sqrt{\frac{\omega}{2D_T}}\right) \sin\left(\omega t + z \sqrt{\frac{\omega}{2D_T}} + \phi\right) \quad (4.2)$$

Figure 4.1 displays typical temperature profiles for different values of the dimensionless depth

$z \sqrt{\frac{\omega}{D_T}}$, based on the following parameter values:

- Average temperature $\tau_{\infty} = 10^\circ\text{C}$
- Amplitude of temperature variation $\tau_M = 15^\circ\text{C}$
- Phase shift $\phi = 0$

The soil insulation delays the temperature fluctuation and reduces its amplitude with increasing depth.

4.2 Vertical Distribution of LNAPL

4.2.1 Overview of LNAPL Distribution in the Capillary Fringe

We model the vertical distribution of free and residual light nonaqueous phase liquid (LNAPL) through the capillary fringe. The LNAPL is immiscible with and less dense than water, so that infiltrating JP4 jet fuel from the fire training pit source spreads out over the water table, subject to retention in the overlying capillary fringe under the action of surface tension

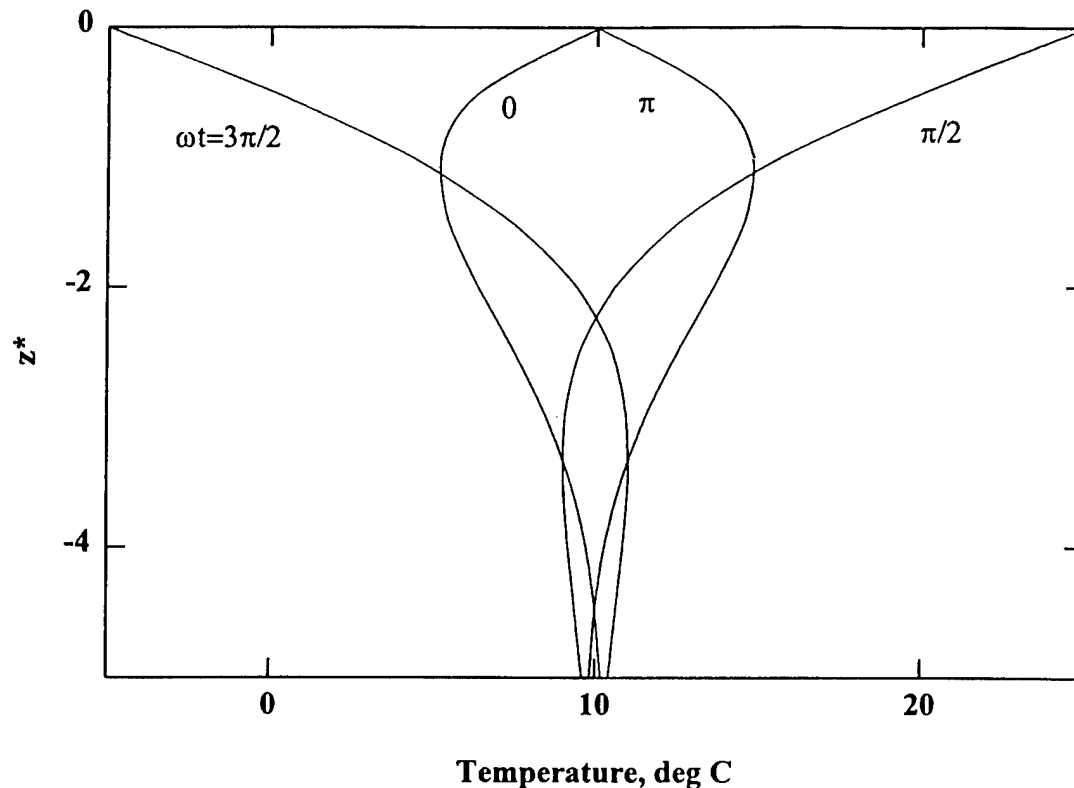


Figure 4.1 Typical Soil Temperature Profiles

[Schwille (1967), Pinder and Abriola (1986)]. The initial spreading of immiscible contaminants through the subsurface as a continuous phase is considered in numerous mathematical [Abriola and Pinder (1985), Corapcioglu and Baehr (1987), Sleep and Sykes (1989)] and laboratory [Schwille (1988), Reibel et al. (1990)] investigations. The dynamic models are complemented by static matrix pressure-saturation characteristic curves for continuous LNAPL-air-water systems, and substantial advances have been achieved in the prediction [Lenhard and Parker (1987,1990)] and laboratory measurement [Lenhard and Parker (1988)] of the necessary constitutive relations. The occurrence and distribution of a discontinuous residual nonaqueous phase liquid has received a degree of theoretical [Parker and Lenhard (1987)] and laboratory study [Wilson and Conrad (1984), Hoag and Marley (1986), Kia and Abdul (1990), Conrad et al. (1992)] comparable to its continuous counterpart.

4.2.2 Free Liquid Retention

A three phase saturation case common to most LNAPL spills exists at Plattsburgh. The usual wetting progression of water-LNAPL-air is in force when free LNAPL is present, and the subsurface is comprised of initially water wet soil, so that water fills all the small pores to an irreducible volumetric water content θ_F . The water is assumed to be continuous over the entire

spatial domain with an apparent [Parker and Lenhard (1987)] effective water saturation S_w that includes the residual LNAPL content θ_{LR} trapped inside the water

$$S_w = \frac{\theta_w + \theta_{LR} - \theta_F}{n - \theta_F} \quad (4.3a)$$

$$\theta_{LR} = \frac{\text{volume} \cdot \text{residual} \cdot \text{LNAPL}}{\text{total} \cdot \text{volume}} \quad (4.3b)$$

The total saturation S includes the LNAPL content, free (θ_{LF}) and residual

$$S = \frac{\theta_w + \theta_{LF} + \theta_{LR} - \theta_F}{n - \theta_F} \quad (4.4a)$$

$$S_{LF} = S - S_w \quad (4.4b)$$

The free LNAPL saturation S_{LF} follows from Eqs. 4.3a and 4.4a.

A van Genuchten (1980) pore size distribution describes all free liquid phases, with scaling factors reflecting capillary pressures and surface tensions across controlling interfaces in accordance with Parker and Lenhard (1987). The total saturation is governed by the LNAPL/air interfacial tension σ_{LA} and the LNAPL matric pressure in the region where free LNAPL is present [Lenhard and Parker (1990)]

$$S = \{1 + [\beta_L (b_L - b)]^{\alpha_p}\}^{1/\alpha_p - 1} \quad (b_L > b > b_M) \quad (4.5a)$$

$$S = 1 \quad (b > b_L) \quad (4.5b)$$

with depth b below the ground surface and free LNAPL extending from b_M to the "LNAPL table" at depth b_L below the ground surface, as sketched in Figure 4.2. The latter parameter marks the surface of free product in a monitoring well.

The pore size uniformity exponent appearing in Equation 4.5 is α_p and the LNAPL scaling factor β_L is related to the mean pore radius r_M by the capillary equation [Streeter and Wylie (1979)] for presumed circular pores and a small contact angle

$$\beta_L = \frac{\rho_L g r_M}{2\sigma_{LA}} \quad (4.6a)$$

$$\sigma_{WA} = \sigma_{LA} + \sigma_{WL} \quad (4.6b)$$

with aviation gasoline density ρ_L and gravitational acceleration g . The water/air surface tension σ_{WA} is equal to the sum of the water/LNAPL tension σ_{WL} and so long as dissolved hydrocarbons do not appreciably alter the interfacial chemistry of the water [Lenhard and Parker (1990)].

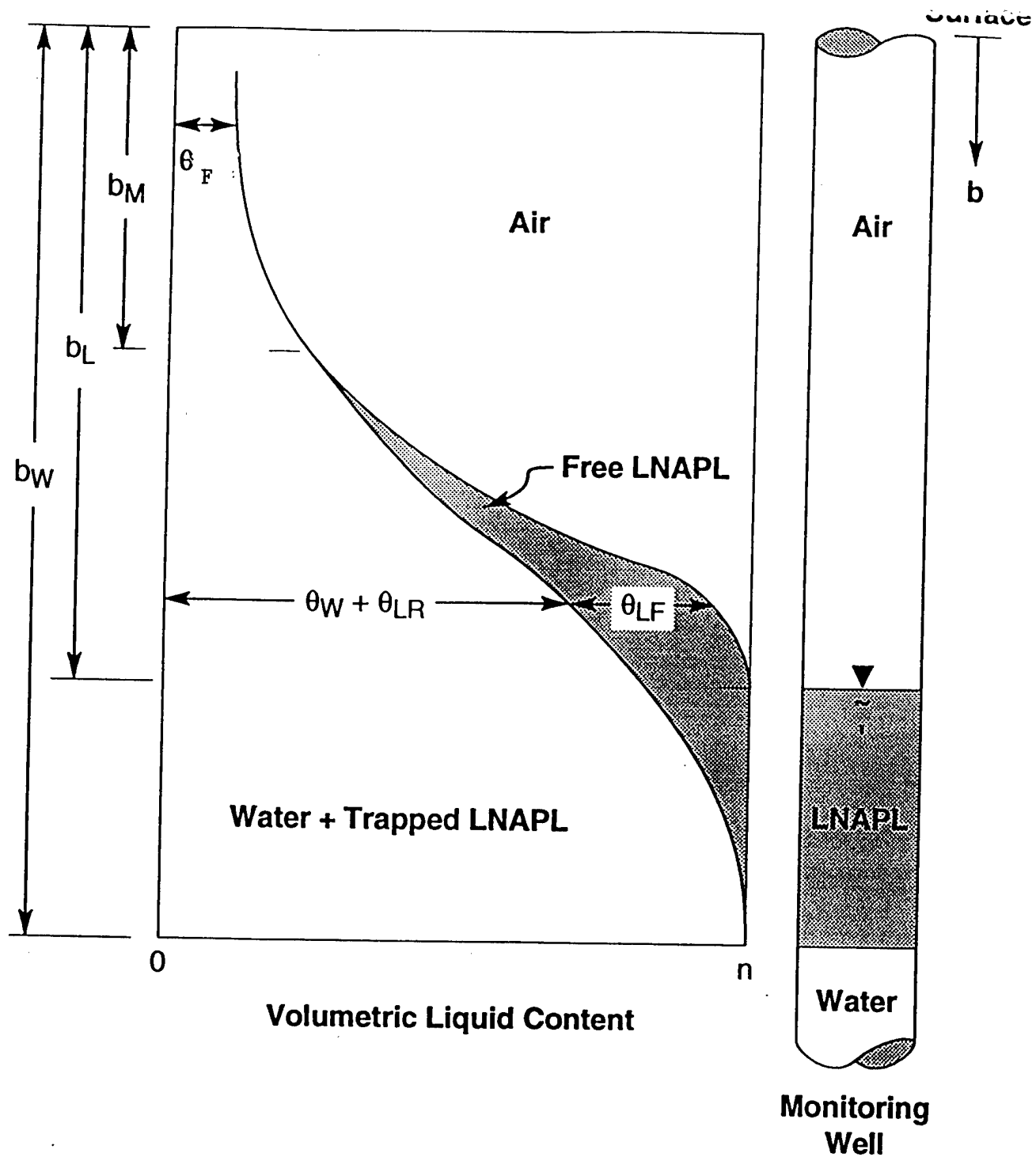


Figure 4.2 Definition Sketch for Three Phase Fluid Distribution in Soil

The apparent effective water saturation is scaled by the LNAPL/water surface tension in the presence of free oil, with a capillary pressure differential across the interface of the two fluids

$$S_w = \{1 + [\beta_w(b_w - b)]^{\alpha_p}\}^{1/\alpha_p - 1} \quad (b_w > b > b_M) \quad (4.7a)$$

$$S_w = 1 \quad (b > b_w) \quad (4.7b)$$

with distance to the water table b_w delineating the thickness ($b_w - b_L$) of free product in a monitoring well. The scaling factor β_w is given by Lenhard and Parker (1990) as

$$\beta_w = \beta_L \frac{(\frac{\rho}{\rho_L} - 1)\sigma_{LA}}{\sigma_{WL}} \quad (4.8)$$

with water density ρ . The free LNAPL persists until the depth b_M , determined by setting S_w and S equal in Equations 4.5a and 4.7a with the result

$$b_M = \frac{\beta_L b_L - \beta_w b_w}{\beta_L - \beta_w} \quad (4.9a)$$

$$p_{WM} = \rho g \varepsilon - \rho_L g (b_w - b_L) \quad (4.9b)$$

$$\varepsilon = b_w - b_M \quad (4.9c)$$

Lenhard and Parker (1990) demonstrate that the water matrix pressure p_{WM} at this depth is equal to the value cited in Equation 4.9b. The distance $b_w - b_M$ corresponds to the free LNAPL contaminated soil interval ε .

The total saturation and water saturation are coincident above b_M as suggested by Figure 4.2, and are governed by the water/air tension and the water matrix pressure p_w . We impose a continuous p_w constraint at b_M and deduce an expression for the apparent effective water saturation in the shallower region from Equations 4.6a and 4.9b

$$p_w = p_{WM} + \rho g (b_M - b) \quad (4.10a)$$

$$S_w = (1 + \{ \frac{\beta_L \sigma_{LA}}{\sigma_{WA}} [b_L - b_w + \frac{\rho}{\rho_L} (b_w - b)] \}^{\alpha_p})^{1/\alpha_p - 1} (b_M > b) \quad (4.10b)$$

Equations 4.7a and 4.10b match at b_M by virtue of Equations 4.8 and 4.9a, ensuring a continuous water saturation profile as well.

The free water and free LNAPL profiles reflect the positions of the LNAPL and water tables at the time of sampling, in contrast to the trapped LNAPL, which is a function of historical fluctuations of these parameters.

4.2.3 LNAPL Entrapment

The residual LNAPL is thought to be the result of hysteretical trapping of JP4 jet fuel as it falls and rises through the water wet soil over a fluctuating water table. The residual LNAPL

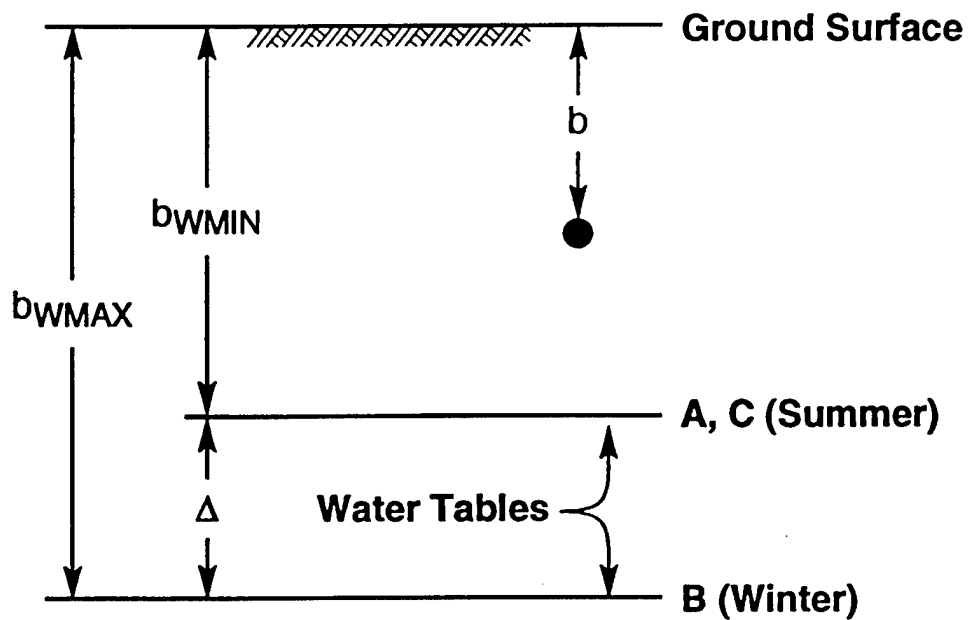
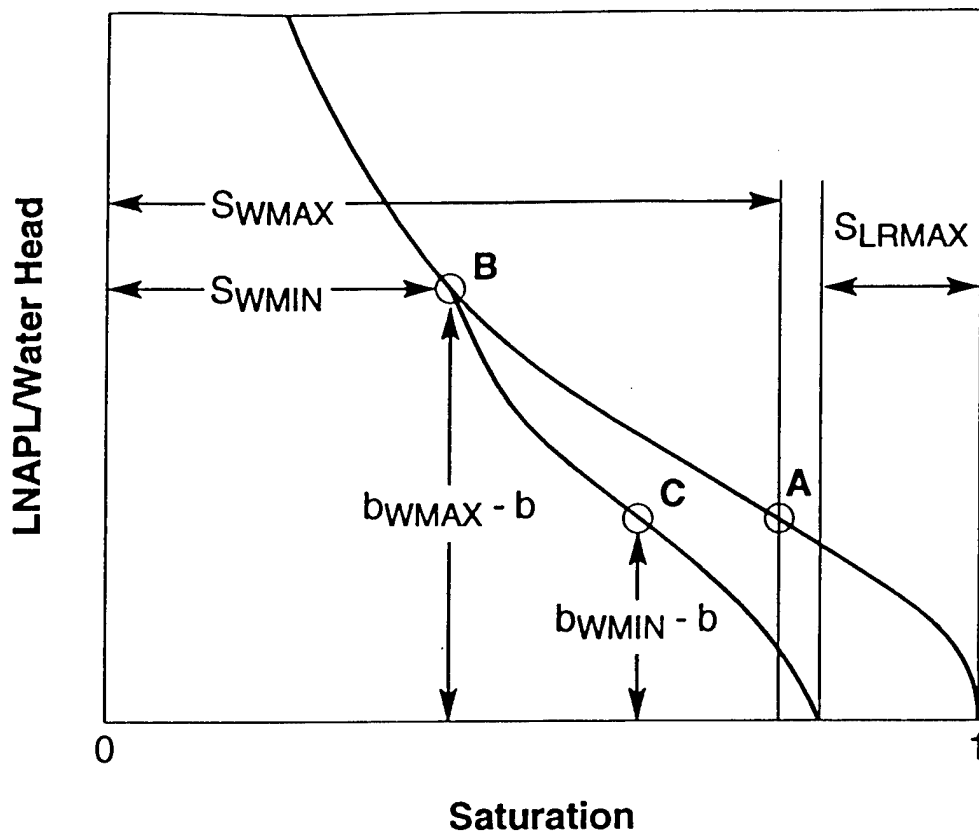


Figure 4.3 Conceptual Diagram of Hysteretical Trapping of LNAPL

saturation S_{LR} reflects the fraction of the drainable pore space that is filled by discontinuous masses of JP4 jet fuel left behind by the process

$$S_{LR} = \frac{\theta_{LR}}{n - \theta_F} \quad (4.11)$$

Parker and Lenhard (1987) suggest that the residual product distribution is governed by the position of the LNAPL/water interface, as tracked by the water saturation and LNAPL/water capillary pressure differential.

Figure 4.3 shows the concept. Available sites at a given depth b drain as the water table drops during the fall months along path AB to its maximum depth b_{WMAX} in the winter at Plattsburgh. The minimum water saturation S_{WMIN} at this reversal point [Parker and Lenhard (1987)] is specified by Equation 4.7a, since free LNAPL is present

$$S_{WMIN} = \{1 + [\beta_w (b_{WMAX} - b)]^{\alpha_p}\}^{1/\alpha_p - 1} \quad (4.12a)$$

$$S_{WMAX} = \{1 + [\beta_w (b_{WMIN} - b)]^{\alpha_p}\}^{1/\alpha_p - 1} \quad (4.12b)$$

$$b_{WMAX} = b_{WMIN} + \Delta \quad (4.12c)$$

Some of the free LNAPL is trapped during spring imbibition as the water table rises along a drier moisture characteristic towards a summer minimum depth b_{WMIN} , defined by the fluctuation amplitude Δ . The minimum water table depth yields a maximum water saturation S_{WMAX} (Equation 4.12b) at the given b value. The hysteretical wetting process yields a maximum trapped LNAPL saturation S_{LRMAX} if the water table rises past the depth b under consideration, as described by Parker and Lenhard (1987)

$$S_{LRMAX} = \frac{1 - S_{WMIN}}{1 + \gamma(1 - S_{WMIN})} \quad (4.13)$$

with the hysteretical factor γ geometrically defined by the primary drainage and imbibition curves. In the absence of detailed field data describing the primary moisture characteristics, γ is calibrated in this study from observed maximum residual saturation data at the site.

Those elevations higher than the minimum water table depth attained during trapping experience occluded masses less than the maximum, in accordance with Parker and Lenhard's (1987) empirical relationship

$$S_{LR} = S_{LRMAX} \left(1 - \frac{1 - S_{WMAX}}{1 - S_{WMIN}}\right) \quad (b < b_{WMIN}) \quad (4.14a)$$

$$S_{LR} = S_{LRMAX} \quad (b_{WMIN} < b < b_{WMAX}) \quad (4.14b)$$

$$S_{LR} = 0 \quad (b_{WMAX} < b) \quad (4.14c)$$

$$S_{LR} = 0 \quad (b < b_{MR}) \quad (4.14d)$$

Equation 4.12c reflects our concern with an LNAPL, which floats on the heavier water, and so is not present below the water table. Free LNAPL must exist at a given location in order for trapping to occur, so that occluded product does not exist above the minimum free product depth b_{MMIN} .

4.3 Analytical Soil Gas Transport Models

4.3.1 Model Overview

We model the transport of soil gas constituents between the top of the capillary fringe at z equals $-b_F$ to the ground surface at z equals 0. Oxygen, helium, carbon dioxide, total hydrocarbon, and trichloroethylene vapor concentrations are considered, as defined by X , H , C , G , and Y

$$C = \frac{\text{mass} \cdot \text{CO}_2}{\text{volume} \cdot \text{soil} \cdot \text{gas}} \quad (m_C = 0.044 \text{ kg/mole}) \quad (4.15a)$$

$$G = \frac{\text{mass} \cdot \text{total} \cdot \text{hydrocarbon} \cdot \text{vapors}}{\text{volume} \cdot \text{soil} \cdot \text{gas}} \quad (m_G = 0.114 \text{ kg/mole}) \quad (4.15b)$$

$$H = \frac{\text{mass} \cdot \text{He}}{\text{volume} \cdot \text{soil} \cdot \text{gas}} \quad (m_H = 0.004 \text{ kg/mole}) \quad (4.15c)$$

$$X = \frac{\text{mass} \cdot \text{O}_2}{\text{volume} \cdot \text{soil} \cdot \text{gas}} \quad (m_X = 0.032 \text{ kg/mole}) \quad (4.15d)$$

$$Y = \frac{\text{mass} \cdot \text{TCE}}{\text{volume} \cdot \text{soil} \cdot \text{gas}} \quad (m_Y = 0.130 \text{ kg/mole}) \quad (4.15e)$$

The molar masses m cited in Equation 4.15 reflect the chemical composition of the vapor--the assumed JP4 jet fuel value corresponds to the molecular weight of volatile alkanes and aromatics.

We consider steady pneumatics and transient gaseous contamination in vertical and cylindrical coordinates. The air porosity is assumed to be uniform, so that the effect of infiltration on the flow of air and contaminants is neglected. Advection and gaseous diffusion are included in the transport model, along with stoichiometrically coupled, first order vapor

reaction rates for oxygen, carbon dioxide, and total hydrocarbons. Trichloroethylene reactions are considered, but on a decoupled basis, since total hydrocarbons are taken as the primary substrate of biodegradation. Helium is used as an abiotic tracer in the modeling efforts, and no reactions disturb its transport. Adsorption is neglected, on the premise of low organics and sandy soil in a moist climate.

4.3.2 Pneumatics

We consider the steady airflow induced by soil venting near the capillary fringe or air sparging at a point below the water table. The volumetric soil gas discharge Q is taken as a constant in either case, neglecting transience and the effect of temperature on air density

$$Q = \text{const} \quad (\text{no boundary}) \quad (4.16a)$$

$$Q = 0 \quad (\text{ambient}) \quad (4.16b)$$

This discharge is assumed to be injected into the subsurface at the capillary fringe edge b_F below the ground surface, and the air flows spherically away from this point in the r' direction

$$v_{R'} = \frac{Q}{2\pi r'^2} \quad (\text{spherical direction}) \quad (4.17)$$

We note that the spherical specific discharge $v_{R'}$ varies inversely with distance r' from the source. The discharge proceeds through a hemisphere in the unsaturated zone. This solution ignores the presence of the ground surface.

Our capillary fringe and ground surface boundaries are in the z plane however, so that a cylindrical coordinate system must be adopted, with radial distance r from the injection point and vertical distance $b_F + z$. These coordinates and the specific discharge components v and w are related to their spherical counterparts by

$$v = v_{R'} \frac{r}{r'} \quad (\text{radial}) \quad (4.18a)$$

$$w = v_{R'} \frac{b_F + z}{r'} \quad (\text{vertical}) \quad (4.18b)$$

$$r'^2 = r^2 + (b_F + z)^2 \quad (4.18c)$$

Equations 4.17 and 4.18 specify the spatial variation of the cylindrical specific discharge components in cylindrical coordinates in the absence of a surface boundary. We superimpose an image sink a distance b_F above the ground to simulate the zero head boundary, with the result

$$v = \frac{Qr}{2\pi} \left\{ \frac{1}{[r^2 + (b_F + z)^2]^{3/2}} - \frac{1}{[r^2 + (b_F - z)^2]^{3/2}} \right\} \quad (\text{with boundary}) \quad (4.19a)$$

$$w = \frac{Q}{2\pi} \left\{ \frac{b_F + z}{[r^2 + (b_F + z)^2]^{3/2}} + \frac{b_F - z}{[r^2 + (b_F - z)^2]^{3/2}} \right\} \quad (\text{with boundary}) \quad (4.19b)$$

4.3.3 Steady Ambient Diffusion and Reaction

Transport simplifies considerably in the absence of airflow and transience, since we have a one dimensional balance of gaseous diffusion and reaction in this case. We write the transport equation and boundary conditions for steady total hydrocarbon concentration G_S

$$D_{GS} \frac{d^2 G_S}{dz^2} = \lambda G_S \quad (\text{ambient}) \quad (4.20a)$$

$$G_S = 0 \quad (z=0) \quad (4.20b)$$

$$G_S = G_F \quad (z=-b_F) \quad (4.20c)$$

with steady total hydrocarbon diffusivity D_{GS} , first order total hydrocarbon degradation rate λ , constant concentration G_O at the origin, and a zero surface condition maintained by rapid atmospheric diffusion. The solution to this homogeneous, linear second order differential equation with constant coefficients is straightforward [Rainville and Bedient (1969)]

$$G_S = G_F \frac{\sinh\left(-z \sqrt{\frac{\lambda}{D_{GS}}}\right)}{\sinh\left(b_F \sqrt{\frac{\lambda}{D_{GS}}}\right)} \quad (\text{ambient}) \quad (4.21)$$

We assume that aerobic biodegradation degrades total hydrocarbons and oxygen to carbon dioxide and water vapor in accordance with



$$\gamma_X = 3.22 \frac{\text{kg} \cdot \text{oxygen}}{\text{kg} \cdot \text{LNAPL}} \quad (4.22b)$$

$$\gamma_C = 2.70 \frac{\text{kg} \cdot \text{carbon} \cdot \text{dioxide}}{\text{kg} \cdot \text{LNAPL}} \quad (4.22c)$$

Oxygen is assumed to diffuse downward from its atmospheric value X_O at the origin. We adopt a (negative) flux $-J_{XO}$ as a second boundary condition, hence

$$D_{XS} \frac{d^2 X_S}{dz^2} = \gamma_X \lambda X_S \quad (\text{ambient}) \quad (4.23a)$$

$$X_S = X_O \quad (z=0) \quad (4.23b)$$

$$-\theta D_{XS} \frac{dX}{dz} = -J_{XO} \quad (z=0) \quad (4.23c)$$

with steady oxygen concentration X_S and diffusivity D_{XS} . The solution to the ambient oxygen transport equation is similar to its hydrocarbon counterpart

$$X_S = X_O \cosh\left(z \sqrt{\frac{\gamma_X \lambda}{D_{XS}}}\right) + \frac{J_{XO}}{\theta \sqrt{\gamma_X \lambda D_{XS}}} \sinh\left(z \sqrt{\frac{\gamma_X \lambda}{D_{XS}}}\right) \quad (4.24)$$

Biodegradation generates carbon dioxide in the subsurface, and it diffuses upward towards a swept boundary condition. The exit flux is taken as stoichiometrically proportional to the oxygen flux consumed in the aerobic degradation process [Ostendorf et al. (1997a)]. The resulting ambient carbon dioxide transport equation is

$$-D_{CS} \frac{d^2 C_S}{dz^2} = \gamma_C \lambda C_S \quad (\text{ambient}) \quad (4.25a)$$

$$C_S = 0 \quad (z=0) \quad (4.25b)$$

$$-\theta D_{CS} \frac{dC_S}{dz} = J_{XO} \frac{\gamma_C}{\gamma_X} \quad (z=0) \quad (4.25c)$$

with steady carbon dioxide concentration C_S and diffusivity D_{CS} . The solution is given by

$$C_S = \frac{\gamma_C J_{XO}}{\gamma_X \theta \sqrt{\gamma_C \lambda D_{CS}}} \sin\left(-z \sqrt{\frac{\gamma_C \lambda}{D_{CS}}}\right) \quad (4.27)$$

Equations 4.21, 4.24, and 4.27 constitute a stoichiometrically coupled system of steady state soil gas profiles describing aerobic transport in the unsaturated zone.

4.3.4 Steady Advection and Diffusion

Helium is injected at a constant rate QH_{INJ} in a series of field tracer experiments, with injection line concentration H_{INJ} . The transport approaches a steady balance of advection and diffusion in spherical coordinates

$$2\pi r'^2 (v_R H_S - \theta D_{\text{HS}} \frac{dH_S}{dr'}) = QH_{\text{INJ}} \quad (\text{steady}) \quad (4.28a)$$

$$H_S = 0 \quad (r'=\infty) \quad (4.28b)$$

with steady helium concentration H_S and diffusivity D_{HS} . We invoke steady pneumatics (Equation 4.17) and derive a general solution to this nonhomogeneous, linear, first order differential equation with variable coefficients [Rainville and Bedient (1969)]

$$H_S = H_{\text{INJ}} [1 - \exp(\frac{-Q}{2\pi\theta D_{\text{HS}} r'})] \quad (\text{steady}) \quad (4.29a)$$

$$H_S = H_{\text{INJ}} \quad (r'=0) \quad (4.29b)$$

The steady helium concentration approaches H_{INF} at a given radius as Q increases and advection dominates.

4.3.5 Unsteady Spherical Advection

The unsteady spherical transport of helium is a balance of storage and advection

$$2\pi r'^2 \theta \frac{\partial H}{\partial t} + \frac{\partial}{\partial r'} (2\pi r'^2 v_R H) = 0 \quad (4.30)$$

This can be solved with the method of characteristics. The helium concentration is constant in a frame of reference traveling with the air molecules at speed v_R/θ away from the injection point. Equation 4.30 becomes

$$\frac{dH}{dt} = 0 \quad (4.31a)$$

$$\frac{dr'_{\text{FRONT}}}{dt} = \frac{v_R}{\theta} \quad (4.31b)$$

$$\frac{dr'_{\text{FRONT}}}{dt} = \frac{Q}{2\pi r'^2_{\text{FRONT}} \theta} \quad (4.31c)$$

The front position r'_{FRONT} establishes the arrival of the source concentration H_F with time from the start of injection. We integrate Equation 4.31 and find

$$H = H_F \quad (r' < r'_{\text{FRONT}}) \quad (4.32a)$$

$$H = 0 \quad (r'_{\text{FRONT}} < r') \quad (4.32b)$$

$$r_{\text{FRONT}} = \left(\frac{3Qt}{2\pi\theta} \right)^{1/3} \quad (4.32c)$$

We use the analytical models to check the accuracy of the finite element soil gas transport model.

4.4 Finite Element Soil Gas Transport Model

4.4.1 Soil Gas Diffusivity Estimation

Millington's (1959) classical gaseous diffusion model is used to characterize the instantaneous hydrocarbon diffusivity D_G in terms of a free air reference value D_{REF}

$$D_G = D_{\text{REF}} \left(\frac{\tau}{\tau_{\infty}} \right)^{7/4} \sqrt{\frac{m_{\text{REF}}}{m_G}} \frac{\theta^{7/3}}{n^2} \quad (4.33a)$$

$$D_{\text{REF}} = 1.90 \times 10^{-5} \frac{\text{m}^2}{\text{s}} \quad (\text{O}_2 \text{ at } 282.14^\circ\text{K}) \quad (4.33b)$$

The reference diffusivity is based on a literature value for oxygen [Weast (1967)], adjusted to the site averaged temperature at Plattsburgh. The temperature and molar mass adjustments are summarized by Reid et al. (1987)--heavy, cold gas molecules diffuse more slowly than light, warm molecules. Molar mass adjustments in Equation 4.30 yield the oxygen and carbon dioxide instantaneous diffusivities.

Equations 4.2 and 4.33a suggest that the seasonal temperature fluctuation imparts a small, depth dependence to the diffusivity. The steady state diffusivities used in ambient profiling incorporate porosity and molecular mass influences but not temperature, since the latter factor is averaged out

$$D_{\text{GS}} = D_{\text{REF}} \sqrt{\frac{m_{\text{REF}}}{m_G}} \frac{\theta^{7/3}}{n^2} \quad (4.34)$$

The steady diffusivities for oxygen (D_{XS}), carbon dioxide (D_{CS}), and helium (D_{HS}) appearing in Equations 4.24, 4.27, and 4.29 follow by substituting the molar mass for oxygen and carbon dioxide into Equation 4.34.

4.4.2 Finite Element Model Formulation

We model air sparging or soil venting from a point source as a transient transport process in cylindrical coordinates, featuring storage, advection, gaseous diffusion, and first order decay. The transport equation for total hydrocarbons is given by

$$\theta \frac{\partial G}{\partial t} + \frac{1}{r} \frac{\partial (vrG)}{\partial r} + \frac{\partial (wG)}{\partial z} - \frac{1}{r} \frac{\partial}{\partial r} (r\theta D_G \frac{\partial G}{\partial r}) - \frac{\partial}{\partial z} (\theta D_G \frac{\partial G}{\partial z}) = -\lambda \theta G \quad (4.35a)$$

$$\frac{\partial}{\partial r} (vrG - r\theta D_G \frac{\partial G}{\partial r}) = 0 \quad (r=0) \quad (4.35b)$$

The no flux boundary condition is imposed on the radial axis, since the source is presumed to lie on the bottom boundary of the domain. The soil gas diffusivity is allowed to vary in the transient domain as well, due to temperature dependence. We use a finite difference approximation to the temporal derivative, predicated on a known prior concentration G_K and a time step Δt

$$\frac{\partial G}{\partial t} \cong \frac{G - G_K}{\Delta t} \quad (4.36a)$$

$$\frac{1}{r} \frac{\partial (vrG)}{\partial r} + \frac{\partial (wG)}{\partial z} - \frac{1}{r} \frac{\partial}{\partial r} (r\theta D_G \frac{\partial G}{\partial r}) - \frac{\partial}{\partial z} (\theta D_G \frac{\partial G}{\partial z}) + \lambda' \theta G = \frac{\theta G_K}{\Delta t} \quad (4.36b)$$

$$\lambda' = \lambda + \frac{1}{\Delta t} \quad (4.36c)$$

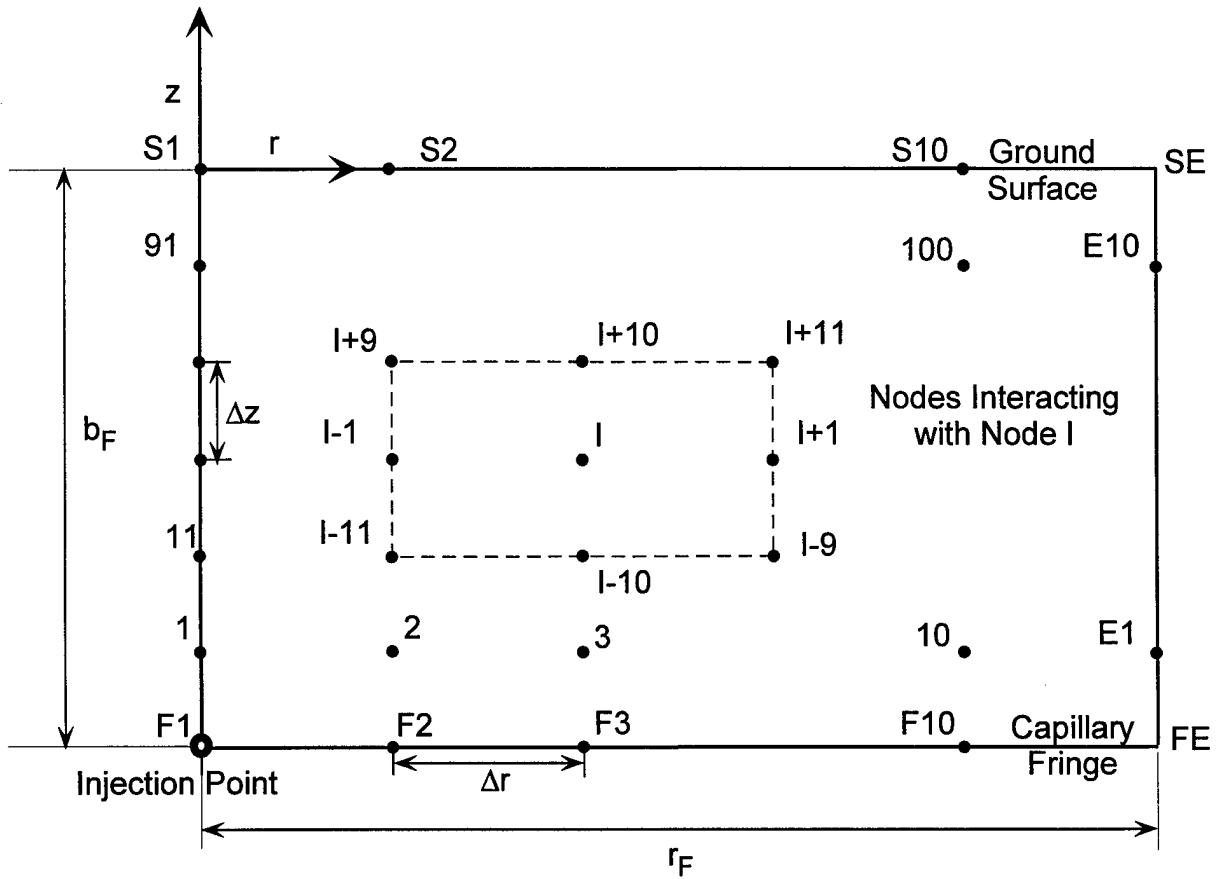
Equation 4.36 is the differential formulation of the transport problem.

We move to a variational formulation by multiplying the transport equation by a weighting function $U(z,r)$, then integrating over the spatial domain [Becker et al. (1981)]. In the latter regard our air flow extends from the top of the capillary fringe at z equals $-b_F$ out to a radius of influence r_F (Figure 4.4)

$$\int_{-b_F}^0 \int_0^{r_F} \left\{ U \frac{\partial}{\partial r} [rvG - \frac{\partial}{\partial r} (r\theta D_G \frac{\partial G}{\partial r})] \right\} dr dz + \int_0^{r_F} \int_{-b_F}^0 \left\{ U \frac{\partial}{\partial z} [wG - \frac{\partial}{\partial z} (\theta D_G \frac{\partial G}{\partial z}) + \lambda' \theta G] \right\} dz dr = \int_0^{r_F} \int_{-b_F}^0 \frac{\theta U G_K}{\Delta t} dz dr \quad (4.37a)$$

$$U = 0 \quad (z=0, z=-b_F, r=r_F) \quad (4.37b)$$

The weighting function is zero on the bottom, top, and outside boundaries of the domain, while the radial flux vanishes at r equals zero. We may accordingly integrate by parts and thereby reduce the order of Equation 4.37a



Note: 100 equispaced nodes in r, z plane.

Figure 4.4 Domain for Finite Element Model

$$\int_0^{r_F} \int_{-b_F}^0 \left\{ \theta D_G \left(\frac{\partial U}{\partial r} \frac{\partial G}{\partial r} + \frac{\partial U}{\partial z} \frac{\partial G}{\partial z} \right) - G \left(v \frac{\partial U}{\partial r} + w \frac{\partial U}{\partial z} \right) + \lambda' \theta U G \right\} dz dr = \int_0^{r_F} \int_{-z_F}^0 \frac{\theta U G_K}{\Delta t} dz dr \quad (4.38)$$

Equation 4.38 is the variational statement of the transport problem.

Galerkin basis functions ϕ_I [Becker et al. (1981)] lead to a finite element formulation. We assume that the weighting function, present, and past concentration may all be expressed as series of basis functions

$$U = \sum_N \phi_I \quad (4.39a)$$

$$G = \sum_N G_J \phi_J \quad (4.39b)$$

$$G_K = \sum_N G_K \phi_K \quad (4.39c)$$

We discretize our domain with a 10 by 10 grid of nodes at locations r_I, z_I , as indicated by Figure 4.4. The nodes are numbered sequentially outwards and are equispaced at increments $\Delta r, \Delta z$, so that adjacent nodes are specified by

$$r_{I+1} - r_I = \Delta r \quad (4.40a)$$

$$z_{I+10} - z_I = \Delta z \quad (4.40b)$$

The basis functions are pyramids that equal unity on the nodes and vanish elsewhere, so that G_J and G_K are the concentrations (present and past) on the nodes

$$\phi_I = \left(\frac{r_{I+1} - r}{\Delta r}\right) \left(\frac{z_{I+10} - z}{\Delta z}\right) \quad (r_I < r < r_{I+1}, z_I < z < z_{I+1}) \quad (4.41a)$$

$$\phi_I = \left(\frac{r - r_{I-1}}{\Delta r}\right) \left(\frac{z_{I+10} - z}{\Delta z}\right) \quad (r_{I-1} < r < r_I, z_I < z < z_{I+1}) \quad (4.41b)$$

$$\phi_I = \left(\frac{r - r_{I-1}}{\Delta r}\right) \left(\frac{z - z_{I-10}}{\Delta z}\right) \quad (r_{I-1} < r < r_I, z_{I-10} < z < z_I) \quad (4.41c)$$

$$\phi_I = \left(\frac{r_{I+1} - r}{\Delta r}\right) \left(\frac{z - z_{I-10}}{\Delta z}\right) \quad (r_I < r < r_{I+1}, z_{I-10} < z < z_I) \quad (4.41d)$$

We note that all the terms in the transport equation contain basis function product terms that are nonzero only when the weighting node (I subscript) is within one node of the concentration nodes (J or K). Figure 4.5 displays the logic of the basis function interaction.

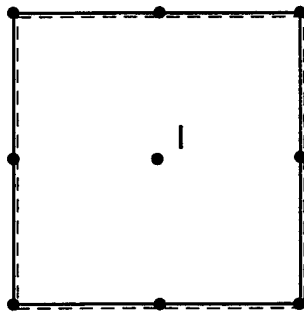
We proceed to the finite element model formulation by substituting Equation 4.39 into 4.38 and integrating term by term

$$\sum_J K_{IJ} G_J = \sum_K F_{IK} G_K + \sum \text{Boundary} \quad (I=1 \text{ to } N) \quad (4.42)$$

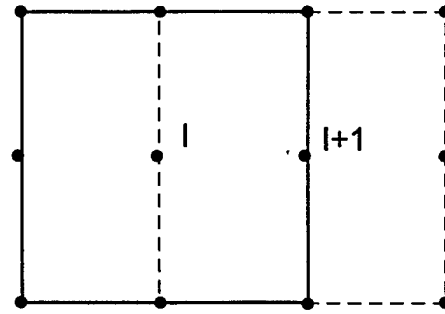
with transport and prior time step arrays K_{IJ} and F_{IK} approximated by

$$K_{IJ} = \int_{\eta-1}^{\eta+1} r \int_{z_{I-10}}^{z_{I+10}} [\theta D_{GI} \left(\frac{\partial \phi_I}{\partial r} \frac{\partial \phi_J}{\partial r} + \frac{\partial \phi_I}{\partial z} \frac{\partial \phi_J}{\partial z} \right) - v \phi_J \frac{\partial \phi_I}{\partial r} - w \phi_J \frac{\partial \phi_I}{\partial z} + \lambda' \theta \phi_I \phi_J] dz dr \quad (4.43a)$$

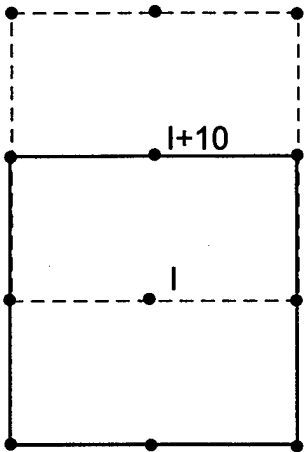
$$F_{IK} = \theta \int_{\eta-1}^{\eta+1} r \int_{z_{I-10}}^{z_{I+10}} \frac{1}{\Delta t} \phi_I \phi_K dz dr \quad (4.43b)$$



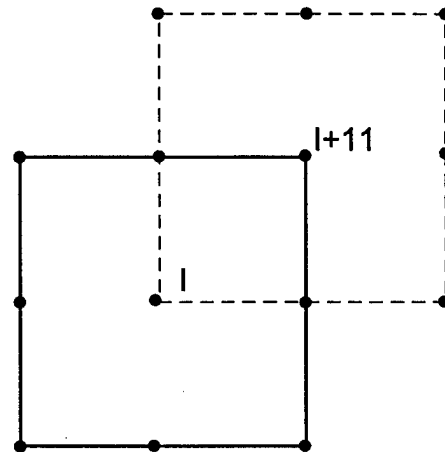
Full Interaction (K_{II})



Radial Interaction (K_{II+1})



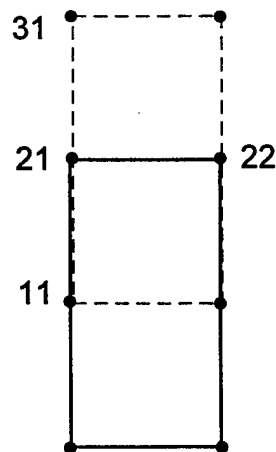
Vertical Interaction (K_{II+10})



Diagonal Interaction (K_{II+11})



Full Boundary Interaction ($K_{11,11}$)



Vertical Boundary Interaction ($K_{11,21}$)

Figure 4.5 Element Interactions

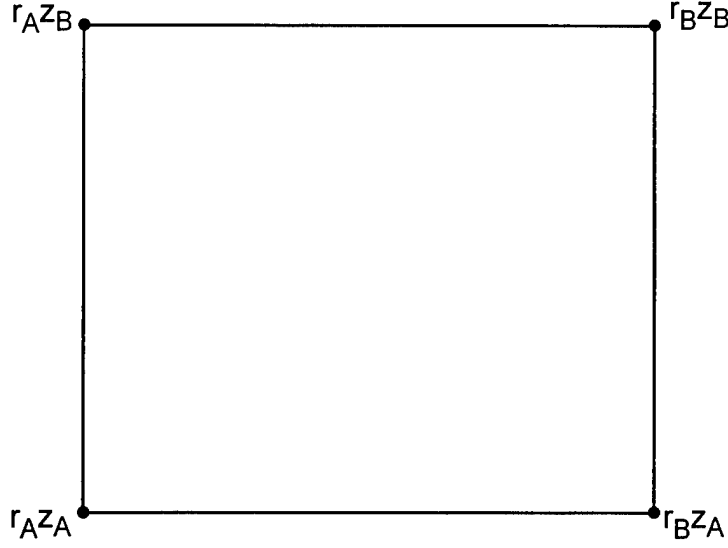


Figure 4.6 Master Element

The integrals in Equation 4.43 are nonzero only for similar or adjacent pairs of interacting nodes. We use the master element shown in Figure 4.6 to evaluate the contribution (e.g., Δk_{AABB}) of adjacent nodes (r_A, z_A and r_B, z_B) to the K_{IJ} (and F_{IK}) arrays. Basis functions may be centered on each corner of the element:

$$\phi_I = \left(\frac{r_B - r}{\Delta r}\right)\left(\frac{z_B - z}{\Delta z}\right) \quad (\text{corner AA}) \quad (4.44a)$$

$$\phi_I = \left(\frac{r - r_A}{\Delta r}\right)\left(\frac{z_B - z}{\Delta z}\right) \quad (\text{corner BA}) \quad (4.44b)$$

$$\phi_I = \left(\frac{r_B - r}{\Delta r}\right)\left(\frac{z - z_A}{\Delta z}\right) \quad (\text{corner AB}) \quad (4.44c)$$

$$\phi_I = \left(\frac{r - r_A}{\Delta r}\right)\left(\frac{z - z_A}{\Delta z}\right) \quad (\text{corner BB}) \quad (4.44d)$$

A similar set of equations is written for ϕ_J (or ϕ_K), inserted into Equation 4.43, and integrated over the master element domain to generate Δk 's (and Δf 's)

$$\Delta k = \int_{r_A}^{r_B} \int_{z_A}^{z_B} [\theta D_{GI} \left(\frac{\partial \phi_I}{\partial r} \frac{\partial \phi_J}{\partial r} + \frac{\partial \phi_I}{\partial z} \frac{\partial \phi_J}{\partial z} \right) - v \phi_J \frac{\partial \phi_I}{\partial r} - w \phi_J \frac{\partial \phi_I}{\partial z} + \lambda' \theta \phi_I \phi_J] dz dr \quad (4.45a)$$

TABLE 4.1 MASTER ELEMENT INTERACTIONS

| Contribution | r_A | z_A | Contribution | r_A | z_A |
|-------------------|------------------|------------------|-------------------|------------------|------------------|
| Δk_{AAAA} | r_I | z_I | Δk_{ABAA} | r_I | $z_I - \Delta z$ |
| Δk_{BBBB} | $r_I - \Delta r$ | $z_I - \Delta z$ | Δk_{BBBA} | $r_I - \Delta r$ | $z_I - \Delta z$ |
| Δk_{ABAB} | r_I | $z_I - \Delta z$ | Δk_{BBAA} | $r_I - \Delta r$ | $z_I - \Delta z$ |
| Δk_{BABA} | $r_I - \Delta r$ | z_I | Δk_{ABBA} | r_I | $z_I - \Delta z$ |
| Δk_{AABA} | r_I | z_I | Δk_{BAAB} | $r_I - \Delta r$ | z_I |
| Δk_{ABBB} | r_I | $z_I - \Delta z$ | Δk_{AABB} | r_I | z_I |
| Δk_{BAAA} | $r_I - \Delta r$ | z_I | Δk_{BABB} | $r_I - \Delta r$ | z_I |
| Δk_{BBAB} | $r_I - \Delta r$ | $z_I - \Delta z$ | Δk_{AAAB} | r_I | z_I |

$$F_{IK} = \theta \int_{\eta_{-1}}^{\eta_{+1}} r \int_{z_{I-10}}^{z_{I+10}} \frac{1}{\Delta t} \phi_I \phi_K dz dr \quad (4.45b)$$

Table 4.1 lists the sixteen possible interactions on the master element, along with the location of the AA corner with respect to the nodal coordinates. We use six point Gauss quadrature [Abramowitz and Stegun (1972)] to approximate the master element integrals, then combine them to generate the interior array elements

$$K_{II} = \Delta k_{AAAA} + \Delta k_{BBBB} + \Delta k_{ABAB} + \Delta k_{BABA} \quad (\text{full interaction}) \quad (4.46a)$$

$$K_{II+1} = \Delta k_{AABA} + \Delta k_{ABBB} \quad (\text{right}) \quad (4.46b)$$

$$K_{II-1} = \Delta k_{BAAA} + \Delta k_{BBAB} \quad (\text{left}) \quad (4.46c)$$

$$K_{II+10} = \Delta k_{AAAB} + \Delta k_{BABB} \quad (\text{up}) \quad (4.46d)$$

$$K_{II-10} = \Delta k_{BBBA} + \Delta k_{ABAA} \quad (\text{down}) \quad (4.46e)$$

$$K_{II+11} = \Delta k_{AABB} \quad (\text{up, right}) \quad (4.46f)$$

$$K_{II+9} = \Delta k_{BAAB} \quad (\text{up, left}) \quad (4.46g)$$

$$K_{II-9} = \Delta k_{ABBA} \quad (\text{down, right}) \quad (4.46h)$$

$$K_{II-11} = \Delta k_{BBAA} \quad (\text{down, left}) \quad (4.46i)$$

We define nonzero ϕ_I basis functions on no flux boundaries, so that partial interaction occurs on the r equals zero axis. This gives rise to partial array elements, since the basis functions do not extend beyond the boundary

$$K_{II} = \Delta k_{AAAA} + \Delta k_{ABAB} \quad (I=1,11,\dots,91) \quad (4.47a)$$

$$K_{II+10} = \Delta k_{AAAB} \quad (4.47b)$$

$$K_{II-10} = \Delta k_{ABAA} \quad (4.47c)$$

A similar set of equations determines F_{IK} . There is no radial interaction between nodes at different elevations in the unsaturated zone (Figure 4.4)

$$K_{II+1} = K_{I+II} = F_{II+1} = F_{I+II} = 0 \quad (I=10,20,30,\dots,90) \quad (4.48)$$

We define boundary nodes on the top, bottom, and outside boundaries of our domain, where the weighting function must vanish and the concentration is known

$$\phi_I = 0; K_{IJ} = F_{IK} = 0 \quad (\text{boundaries}) \quad (4.49a)$$

$$G = G_{INJ} \quad (I=F1) \quad (4.49b)$$

$$G_I = G_O \quad (I=F2,F3,\dots,F10,FE) \quad (4.49c)$$

$$G_I = G_E \quad (I=E1,E2,\dots,E10) \quad (4.49d)$$

$$G_I = 0 \quad (I=S1,S2,\dots,S10,SE) \quad (4.49e)$$

The injection concentration is centered on node F1, while Equation 4.21 specifies the outside (ambient) boundary nodal concentrations G_E on nodes E1-E10. The remaining nodes on the ground surface are pure, while the ambient G_O concentration exists on the capillary fringe away from the source.

The known boundary concentration terms comprise the boundary vector $\Sigma\text{Boundary}$ on the right hand side of Equation 4.42. The bottom boundary requires downward interaction with the source and bottom nodes

$$\Sigma \text{ Boundary} = G_{INJ}(F_{IF1} - K_{IF1}) + G_{F2}(F_{2F1} - K_{2F1}) \quad (I=1) \quad (4.50a)$$

$$\Sigma \text{ Boundary} = G_{FI-1}(F_{IFI-1} - K_{IFI-1}) + G_{FI}(F_{IFI} - K_{IFI}) + G_{FI+1}(F_{IF+1} - K_{IF+1}) \quad (I=2..9) \quad (4.50b)$$

$$\begin{aligned} \Sigma \text{ Boundary} = & G_{F9}(F_{10F9} - K_{10F9}) + G_{F10}(F_{10F10} - K_{10F10}) + G_{FE}(F_{10FE} - K_{10FE}) \\ & + G_{E1}(F_{10E1} - K_{10E1}) + G_{E2}(F_{10E2} - K_{10E2}) \quad (I=10) \end{aligned} \quad (4.50c)$$

The corner node 10 interacts with nodes on the bottom and outside boundaries, with outside concentration G_E specified by Equation 4.21. The remaining outside nodes are given by

$$\Sigma \text{ Boundary} = G_{EI-1}(F_{IEI-1} - K_{IEI-1}) + G_{EI}(F_{IEI} - K_{IEI}) + G_{EI+1}(F_{IEI+1} - K_{IEI+1}) \quad (I=20,30..90) \quad (4.51)$$

The surface boundary contributions are listed for completeness, although most terms are zero

$$\Sigma \text{ Boundary} = (0)[(F_{9IS1} - K_{9IS1}) + (F_{9IS2} - K_{9IS2})] \quad (I=91) \quad (4.52a)$$

$$\Sigma \text{ Boundary} = (0)[(F_{ISI-1} - K_{ISI-1}) + (F_{ISI} - K_{ISI}) + (F_{ISI+1} - K_{ISI+1})] \quad (I=92,93..99) \quad (4.52b)$$

$$\begin{aligned} \Sigma \text{ Boundary} = (0)[(F_{100S9} - K_{100S9}) + (F_{100S10} - K_{100S10}) + (F_{100SE} - K_{100SE})] + \\ + G_{E10}(F_{100E10} - K_{100E10}) + G_{E9}(F_{100E9} - K_{100E9}) \quad (I=100) \end{aligned} \quad (4.52c)$$

Equation 4.42 represents 100 simultaneous equations for 100 unknown nodal concentrations. We use Gauss elimination to generate G_j for each time step, starting with a known initial condition

$$G = G_K \quad (t=0) \quad (4.53)$$

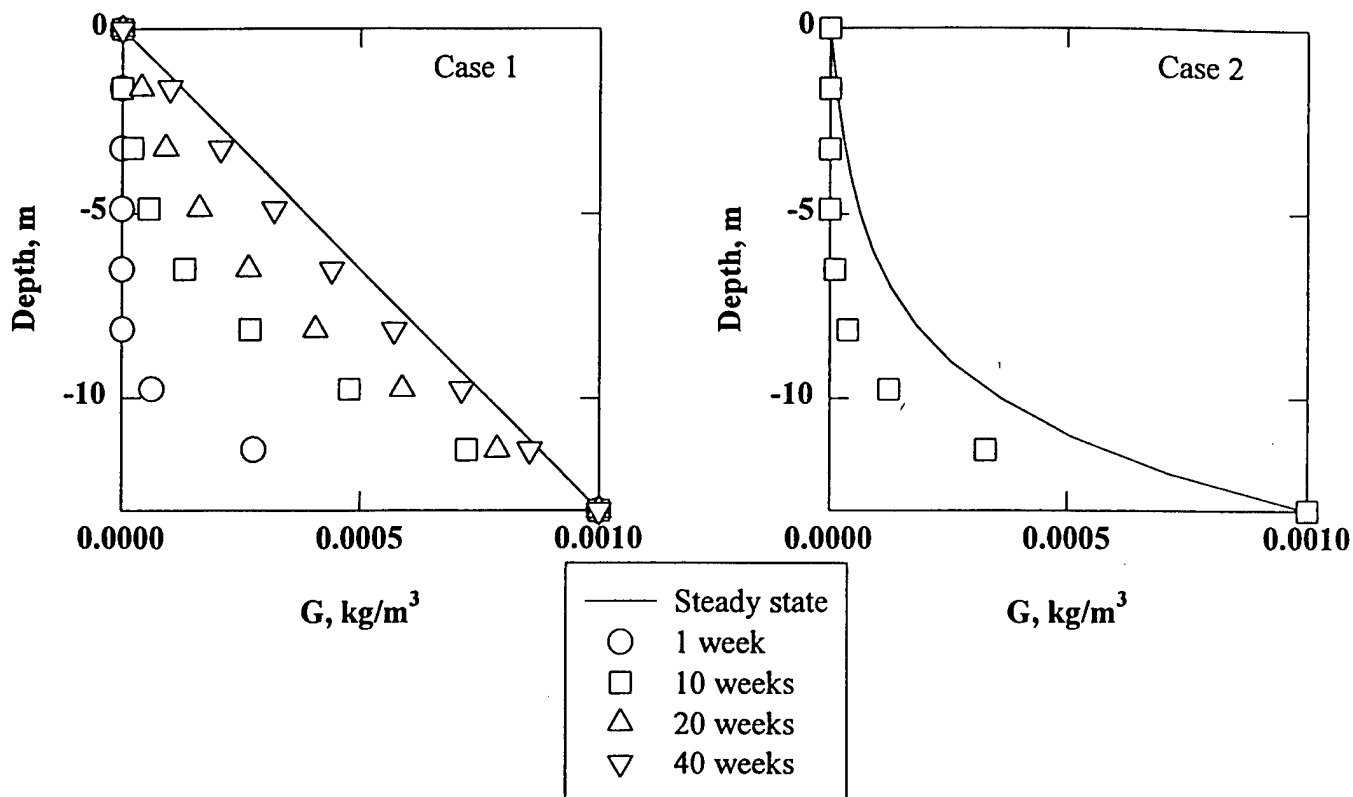
4.4.3 Simulations and Sensitivity

Table 4.2 lists four simulations used to check the model accuracy as well as its sensitivity to transport parameter values. We note the following common values in the simulations:

Common Parameter Values for Simulations

- Initial condition $G_K=0$
- Air porosity $\theta = 0.288$
- Time step $\Delta t=1$ week
- Temperature fluctuation $\tau_M=12^\circ\text{K}$
- Average temperature $\tau_\infty=282^\circ\text{K}$
- Phase $\phi=0$ rad
- Thermal diffusivity $D_T=1.74 \times 10^{-6} \text{ m}^2/\text{s}$

Cases 1 and 2 represent one dimensional diffusion of total hydrocarbon vapors from the fringe to the ground surface. Case 1 constitutes conservative transport. Since the initial condition is a pure unsaturated zone, this case also illustrates the diffusive response time t_{DIF} of the vadose zone. Figure 4.7 displays the analytical (Equation 4.21) and numerical profiles at various times. The transient profile approaches the steady, linear profile after about 40 weeks of gaseous diffusion, a slow response time reflective of the deep unsaturated zone assumed in the simulation. These results are confirmed by an order of magnitude estimate of the diffusive penetration time t_{DIF}



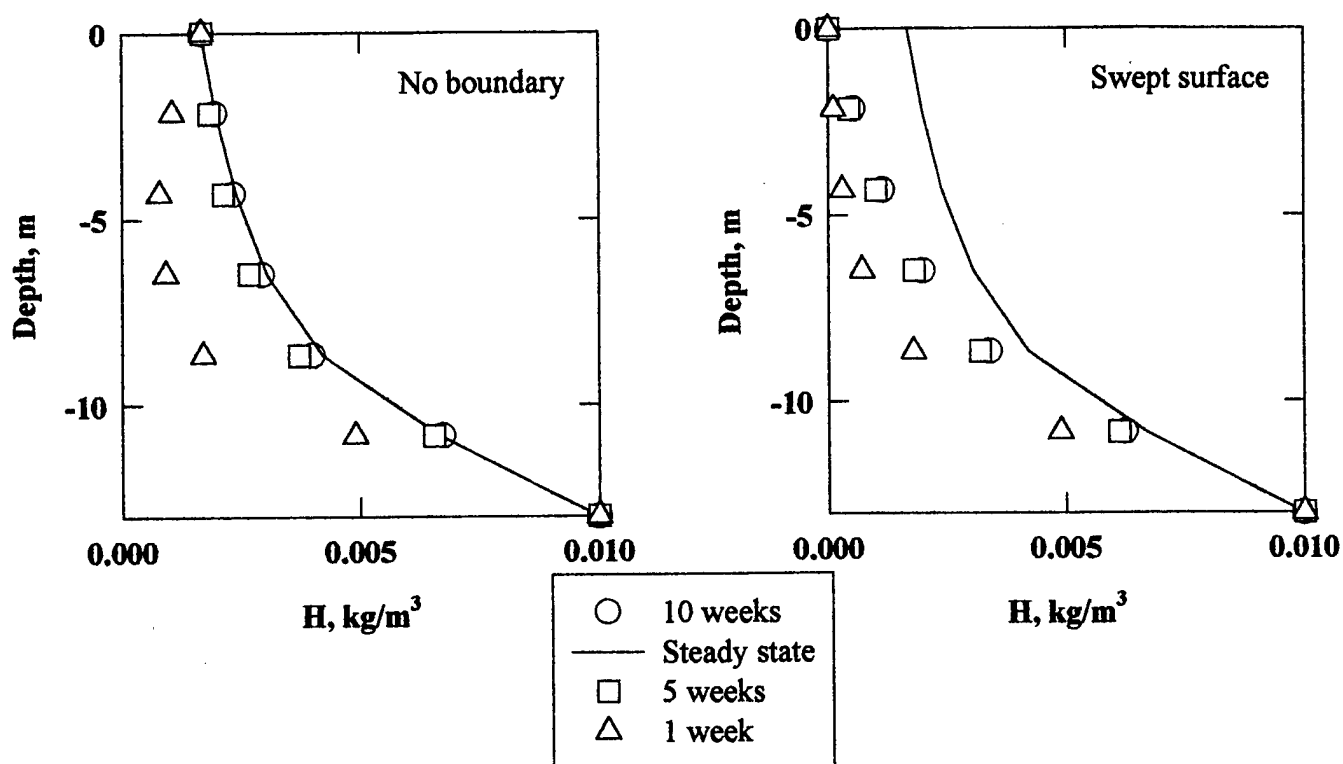
Note: Profiles computed at $r=4.28$ m

Figure 4.7 Steady State Analytical (Solid Curve) and Transient Finite Element (Symbols) Hydrocarbon Vapor Profiles

$$t_{DIF} \approx \frac{b_F^2}{D_{GS}} \quad (4.54)$$

Case 2 demonstrates the role of reactions, which lower the unsaturated zone concentrations below the conservative values. Concentrations do not persist over the entire depth of the unsaturated zone under strongly reactive conditions, and the profile is nonlinear. With the unsaturated zone thickness of order 10 m and the hydrocarbon diffusivity of order $5 \times 10^{-6} \text{ m}^2/\text{s}$ in magnitude, Eq. 4.54 suggests that vapors will diffuse to the ground surface about 30 weeks after evaporation from the capillary fringe. We include a listing of the QBASIC compute code used to simulate the no advection case in Appendix V.

Cases 3 and 4 examine the role of helium advection. A no flow boundary condition is imposed on the capillary fringe, and helium is injected at a constant rate and concentration in the lower inside node of the domain (Figure 4.4). Case 3 simulates an infinite domain (as a check on



Note: Profiles computed at $r=0$ m

Figure 4.8 Steady State Analytical (Solid Curve) and Transient Finite Element (Symbols) Helium Vapor Profiles

TABLE 4.2 SENSITIVITY STUDY OF SOIL GAS TRANSPORT

| Parameter | Case 1 | Case 2 | Case 3 | Case 4 |
|-------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|
| Contaminant | Hydrocarbons | Hydrocarbons | Helium | Helium |
| λ, s^{-1} | 0 | 5×10^{-7} | 0 | 0 |
| $Q, m^3/s$ | 0 | 0 | 0.0001 | 0.0001 |
| $D_S, m^2/s$ | $(D_{GS}) 4.37 \times 10^{-6}$ | $(D_{GS}) 4.37 \times 10^{-6}$ | $(D_{HS}) 2.33 \times 10^{-5}$ | $(D_{HS}) 2.33 \times 10^{-5}$ |
| $c_O, kg/m^3$ | $(G_O) 0.001$ | $(G_O) 0.001$ | No flux | No flux |
| $c_F, kg/m^3$ | 0 | 0 | $(H_{INF}) 0.01$ | $(H_{INF}) 0.01$ |
| b_F, m | 13 | 13 | No boundary | 13 |
| r_E, m | 15 | 15 | No boundary | 25 |

the numerical model) by setting the surface and outside boundary node concentrations equal to steady state values (Equation 4.29a). Concentrations return to their steady values within a 10 weeks period for case 3, in accordance with an advective time scale (residence time) t_{ADV} computed in accordance with

$$t_{ADV} \approx \frac{4\pi\theta b_F^3}{3Q} \quad (4.55)$$

The finite element model accurately simulates the analytical model. Case 4 illustrates the effect of a swept surface on helium transport. The atmosphere increases the concentration gradient and the diffusive flux as a consequence, lowering soil gas concentrations throughout the unsaturated zone.

The advective diffusive finite element transport model computer code is listed in Appendix V.

4.5 Boundary Flux Models

The near surface array and the vapor probes provide resolved vertical soil gas concentration profiles through the root zone and capillary fringe, respectively. We derive quasi steady, vertical transport models near these two boundaries to supplement the finite element code.

4.5.1 Trichloroethylene Vapor Transport through the Root Zone

We model trichloroethylene vapor transport through the root zone as a quasi steady, one dimensional balance of advection, diffusion, and first order decay

$$w_O \frac{dY}{dz} - \theta D_Y \frac{d^2Y}{dz^2} = -\theta \lambda_{TCE} Y \quad (\text{near surface}) \quad (4.56a)$$

$$Y = 0 \quad (z=0) \quad (4.56b)$$

$$Y = Y_O \quad (z=-b_R) \quad (4.56c)$$

with constant near surface vertical specific discharge w_O , and first order TCE degradation rate λ_{TCE} . The trichloroethylene concentration approaching the root zone Y_O , and the root zone thickness is b_R .

The solution to this second order, linear, homogeneous, ordinary differential equation with constant coefficients is given by [Rainville and Bedient (1969)]

$$Y = Y_O \exp\left[\frac{w_O(z + b_R)}{2\theta D_Y}\right] \left[\frac{\sinh\left(-\frac{w_O z}{2\theta D_Y} \sqrt{1 + \frac{4\lambda_{TCE}\theta^2 D_Y}{w_O^2}}\right)}{\sinh\left(\frac{w_O b_R}{2\theta D_Y} \sqrt{1 + \frac{4\lambda_{TCE}\theta^2 D_Y}{w_O^2}}\right)} \right] \quad (4.57)$$

4.5.2 Vapor Transport near the Capillary Fringe

The transport of soil gas constituents immediately above the capillary fringe is dominated by vertical concentration gradients. We ignore reactions and radial and temporal variability, so that total hydrocarbons are described by a constant flux layer governing equation

$$w_F G - \theta D_G \frac{dG}{dz} = J_{GF} \quad (\text{near fringe}) \quad (4.58a)$$

$$G = G_F \quad (z = -b_F) \quad (4.58b)$$

with characteristic vertical specific discharge w_F , hydrocarbon concentration G_F on the capillary fringe boundary, and hydrocarbon flux J_{GF} entering the fringe. The simple solution is

$$G = \frac{J_{GF}}{w_F} + \left(G_F - \frac{J_{GF}}{w_F}\right) \exp\left[\frac{w_F(z + b_F)}{\theta D_G}\right] \quad (\text{near fringe}) \quad (4.59)$$

5 RESULTS

5.1 Soil Temperature, Grain Size Distribution, and Moisture Content

5.1.1 Soil Temperature

Table 5.1 lists soil temperatures observed in the thermocouple arrays in boreholes SPK and 12AT from October 1995 to December 1996. A sinusoidal temporal variation is evident, with a phase shift and a dampened amplitude with depth. Indeed, soil insulation reduces the amplitude of the seasonal temperature fluctuation from 14 °K at the ground surface to 1.2 °K at a depth of 10 m. The time of maximum temperature at the 10 m depth lags the surface occurrence by 2.4 rads, or 139 days.

We calibrate the theory of Section 4.1 with these data, based on the following adopted parameter values:

$$\omega = 1.99 \times 10^{-7} \frac{\text{rad}}{\text{s}} \quad (\text{annual frequency}) \quad (5.1a)$$

$$\tau_{\infty} = 282.14^{\circ} \text{K} \quad (\text{average temperature}) \quad (5.1b)$$

$$\phi = 2.1 \text{ rad} \quad (\text{phase shift}) \quad (5.1c)$$

$$\text{temporal origin} = 1 \text{ September } 95 \quad (5.1d)$$

We optimize the thermal error mean δ_{TM} and standard deviation σ_T by a nested Fibonacci search [Beveridge and Schechter (1979)] for thermal diffusivity and seasonal disturbance amplitude, with the error statistics defined by [Benjamin and Cornell (1970)]

$$\delta_T = \frac{\tau(\text{measured}) - \tau(\text{predicted})}{\tau_{\infty}} \quad (5.2a)$$

$$\delta_{TM} = \frac{1}{N} \sum_N \delta_T \quad (5.2b)$$

$$\sigma_T = \sqrt{\frac{1}{N} \sum_N \delta_T^2 - \delta_{TM}^2} \quad (5.2c)$$

Figure 5.1 displays the observed and calibrated temperature profiles resulting from the search, which results in the the following parameter values:

$$D_T = 1.74 \times 10^{-6} \frac{\text{m}^2}{\text{s}} \quad (5.3a)$$

TABLE 5.1 SOIL TEMPERATURE DATA^a

| Depth, m | 13Oct95 | 2Nov95 | 18Nov95 | 2Dec95 | 17Jan96 | 7Feb96 | 1Mar96 |
|----------|-----------------|--------|---------|--------|---------|--------|--------|
| SPK1-0.3 | 13.7 | 6.8 | 1.8 | -0.1 | -0.2 | -5.6 | -4.5 |
| 0.60 | 13.8 | 8.2 | 3.6 | 1.2 | 0.7 | -2.9 | -1.9 |
| 0.90 | 14.1 | 10.2 | 5.8 | 3.4 | 1.8 | -0.1 | -1.2 |
| 1.20 | 14.4 | 11.4 | 7.4 | 4.9 | 2.6 | 1.0 | -0.5 |
| 1.50 | 14.5 | 12.1 | 8.4 | 6.1 | 3.2 | 1.7 | 0.0 |
| 1.80 | 14.7 | 12.4 | 9.3 | 6.8 | 3.7 | 2.3 | 0.5 |
| 2.10 | 14.7 | 12.9 | 10.2 | 7.9 | 4.7 | 3.1 | 1.3 |
| 2.40 | 14.8 | 13.2 | 10.8 | 8.7 | 5.3 | 3.6 | 2.1 |
| 2.70 | 14.7 | 13.2 | 11.3 | 9.4 | 6.0 | 4.2 | 2.6 |
| 3.00 | 14.4 | 13.3 | 11.6 | 10.0 | 6.6 | 4.7 | 3.2 |
| 4.60 | 13.3 | 12.7 | 12.1 | 11.3 | 8.5 | 6.9 | 5.7 |
| 6.10 | 11.6 | 11.2 | 11.1 | 11.1 | 9.6 | 8.2 | 7.3 |
| 7.60 | 10.4 | 9.7 | 9.9 | 10.3 | 9.6 | 8.7 | 8.1 |
| 9.10 | 9.6 | 8.9 | 9.2 | 9.6 | 9.3 | 8.6 | 8.2 |
| 10.7 | 9.3 | 8.3 | 8.5 | 9.1 | 8.7 | 8.0 | 8.0 |
| 12AT-0.6 | NS ^b | NS | NS | 0.9 | 0.4 | -4.2 | -3.4 |
| 1.20 | NS | NS | NS | 3.3 | 1.3 | -0.3 | -2.3 |
| 1.80 | NS | NS | NS | 5.7 | 2.8 | 1.6 | -0.7 |
| 2.40 | NS | NS | NS | 7.7 | 4.6 | 3.1 | 1.1 |
| 3.00 | NS | NS | NS | 9.2 | 6.2 | 4.3 | 2.1 |
| 4.60 | NS | NS | NS | 10.7 | 8.3 | 6.6 | 4.5 |
| 6.10 | NS | NS | NS | 11.0 | 9.9 | 8.3 | 6.5 |
| 7.60 | NS | NS | NS | 10.4 | 10.2 | 9.2 | 7.7 |
| 9.10 | NS | NS | NS | 9.5 | 9.8 | 9.4 | 8.3 |

^adeg C.

^bNot sampled.

$$\tau_M = 14.0^\circ \text{K} \quad (5.3b)$$

The fit is excellent, as evidenced by an error standard deviation of 0.5%. The insulating effect of the soil is evident in the figure--soil temperature fluctuations are damped and delayed with increasing depth in the soil.

Table 5.2 compares the Plattsburgh thermal profile parameters with values from two sites in eastern Massachusetts [Ostendorf et al. (1995c, 1997b)]. All three profiles have a surface temperature equal to the average value at the end of April, reflecting Spring warming in the northern hemisphere. The Massachusetts average temperatures are nearly 2 °K warmer than the Plattsburgh average, due to their more southerly location. We also note that the proximity of the

TABLE 5.1 (Continued) SOIL TEMPERATURE DATA^a

| Depth, m | 21Mar96 | 4Apr96 | 5May96 | 20Jun96 | 9Aug96 | 21Aug96 | 17Oct96 |
|----------|-----------------|--------|--------|---------|--------|---------|---------|
| SPK1-0.3 | NS ^b | 2.9 | 11.0 | 22.3 | 27.5 | 29.9 | 14.0 |
| 0.60 | -0.8 | 2.0 | 9.8 | 19.4 | 20.9 | 21.9 | 11.6 |
| 0.90 | -1.3 | 0.4 | 8.1 | 17.0 | 19.0 | 20.4 | 12.8 |
| 1.20 | 0.6 | 0.0 | 6.9 | 15.1 | 17.5 | 19.6 | 13.7 |
| 1.50 | 0.2 | 0.1 | 6.2 | 13.7 | 16.4 | 18.9 | 14.3 |
| 1.80 | 1.9 | 0.3 | 6.0 | 12.7 | 15.7 | 18.3 | 14.7 |
| 2.10 | 3.0 | 0.6 | 5.6 | 11.6 | 14.7 | 17.6 | 14.8 |
| 2.40 | 3.4 | 1.0 | 5.2 | 10.6 | 13.7 | 16.6 | 15.1 |
| 2.70 | 3.9 | 1.7 | 5.1 | 9.7 | 12.9 | 16.1 | 15.1 |
| 3.00 | 4.3 | 2.2 | 4.9 | 8.8 | 12.3 | 15.3 | 14.9 |
| 4.60 | 6.4 | 4.4 | 5.4 | 6.9 | 9.5 | 12.5 | 13.7 |
| 6.10 | 8.5 | 6.1 | 6.8 | 6.5 | 7.7 | 10.4 | 11.9 |
| 7.60 | 9.2 | 7.3 | 7.9 | 7.0 | 7.0 | 9.3 | 10.5 |
| 9.10 | 9.2 | 7.7 | 8.4 | 7.5 | 6.9 | 8.8 | 14.1 |
| 10.7 | 9.0 | 7.7 | 8.6 | 7.8 | 6.9 | 6.9 | 9.3 |
| 12AT-0.6 | -0.6 | 2.9 | 10.0 | 20.0 | 21.6 | 21.4 | 14.1 |
| 1.20 | 0.0 | 1.9 | 7.9 | 17.1 | 19.0 | 19.7 | 12.4 |
| 1.80 | 1.2 | 1.8 | 6.3 | 14.2 | 16.6 | 18.2 | 13.8 |
| 2.40 | 2.4 | 2.4 | 5.3 | 11.6 | 14.6 | 16.8 | 14.6 |
| 3.00 | 3.1 | 3.3 | 4.9 | 9.8 | 13.1 | 15.4 | 15.1 |
| 4.60 | 5.6 | 5.5 | 5.0 | 7.9 | 10.4 | 12.6 | 14.3 |
| 6.10 | 8.0 | 7.3 | 6.3 | 7.2 | 8.6 | 10.2 | 12.9 |
| 7.60 | 9.3 | 8.6 | 7.9 | 7.6 | 7.9 | 9.1 | 11.4 |
| 9.10 | 9.3 | 9.1 | 8.9 | 8.4 | 7.9 | 8.7 | 10.4 |

^adeg C.

^bNot sampled.

ocean moderates the fluctuation amplitude at the coastal sites, so that the Plattsburgh τ is higher than the Massachusetts values. The calibrated thermal diffusivity for Plattsburgh is comparable to the sandy site value at Plymouth, and somewhat larger than the silty sand D_T for Boston. This finding is consistent with Hillel (1982), who notes that finer grained soils tend to have lower thermal diffusivities.

We substitute Equations 5.1 and 5.3 into Equation 4.2 in order to estimate temperature effects on gas concentration (through the ideal gas law) and gaseous diffusivity in the analysis of gas transport, once the moisture and grain size data have been presented.

5.1.2 Grain Size Distribution

TABLE 5.1 (Continued) SOIL TEMPERATURE DATA^a

| Depth, m | 7Nov96 | 20Nov96 | 19Dec96 | Depth, m | 7Nov96 | 20Nov96 | 19Dec96 |
|----------|--------|---------|---------|----------|-----------------|---------|---------|
| SPK1-0.3 | 14.1 | 8.7 | 3.0 | 7.60 | 10.7 | 12.1 | 11.0 |
| 0.60 | 11.0 | 5.2 | 4.0 | 9.10 | 9.8 | 11.1 | 10.0 |
| 0.90 | 9.1 | 7.4 | 2.0 | 10.7 | 9.2 | 10.4 | 9.0 |
| 1.20 | 13.6 | 9.1 | 5.0 | 12AT-0.6 | NS ^b | NS | NS |
| 1.50 | 11.2 | 10.1 | 6.0 | 13.7 | 9.1 | 6.1 | 4.3 |
| 1.80 | 11.6 | 11.0 | 6.0 | 12.7 | 11.1 | 8.8 | 5.9 |
| 2.10 | 12.2 | 11.9 | 7.0 | 11.6 | 12.2 | 10.6 | 7.6 |
| 2.40 | 12.7 | 12.5 | 8.0 | 10.6 | 12.9 | 11.7 | 8.8 |
| 2.70 | 12.9 | 12.9 | 9.0 | 9.7 | 13.4 | 12.7 | 10.9 |
| 3.00 | 13.1 | 13.3 | 9.0 | 8.8 | 12.8 | 12.8 | 11.9 |
| 4.60 | 13.1 | 13.7 | 11.0 | 11.5 | 9.5 | 12.2 | 12.0 |
| 6.10 | 11.9 | 13.2 | 11.0 | 10.5 | 7.7 | 10.7 | 11.3 |

^adeg C.

^bNot sampled.

TABLE 5.2 THERMAL PROFILE PARAMETERS

| Reference | Location | Zero Date | Soil Type | D _T , m ² /s | τ _M , °K | τ _∞ , °K |
|--------------------------|---------------|-----------|------------|------------------------------------|---------------------|---------------------|
| This site | Plattsburgh | 30 April | Sand | 1.73x10 ⁻⁶ | 14.0 | 282.1 |
| Ostendorf et al. (1995c) | Lexington, MA | 3 May | Silty sand | 1.11x10 ⁻⁶ | 10.8 | 284.0 |
| Ostendorf et al. (1997b) | Plymouth, MA | 21 April | Sand | 1.46x10 ⁻⁶ | 12.7 | 283.6 |

We focus our efforts on the unsaturated zone, which consists of uniform coarse sand. A van Genuchten (1980) grain size distribution is fit to grain size data from 111 split spoon samples in boreholes SPK1, SPK2, and 12AY (Figure 3.1)

$$F(D) = (1 + D^{-\alpha_D})^{\frac{1}{\alpha_D} - 1} \quad (\alpha_D > 1) \quad (5.4a)$$

$$D = \frac{d}{d_M} \quad (5.4b)$$

with cumulative density function $F(D)$, dimensionless grain size D , dimensional grain size d , mean grain size d_M , and grain size uniformity exponent α_D . The mean grain size and the uniformity exponent are varied to minimize the error mean δ_{DM} and standard deviation σ_D by a nested Fibonacci search, with error statistics defined by

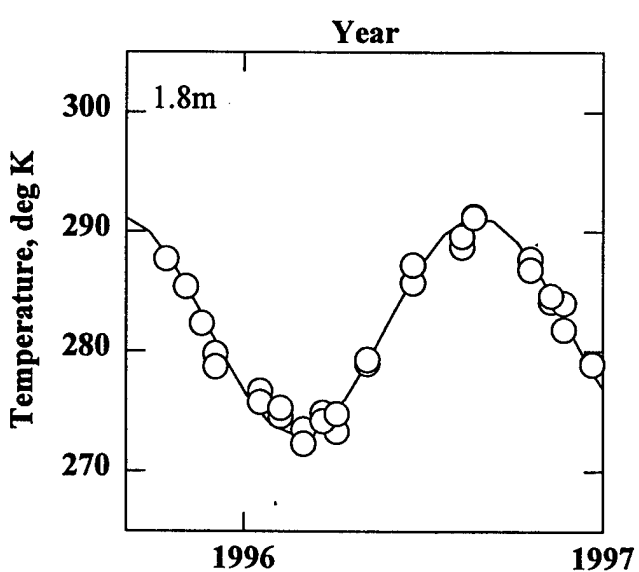
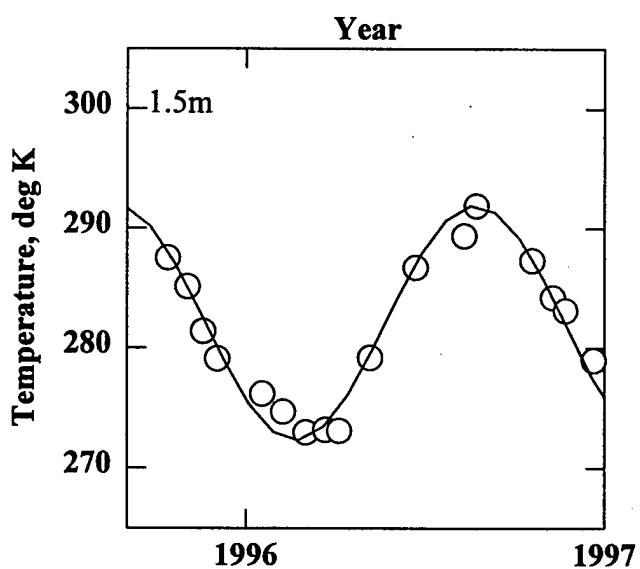
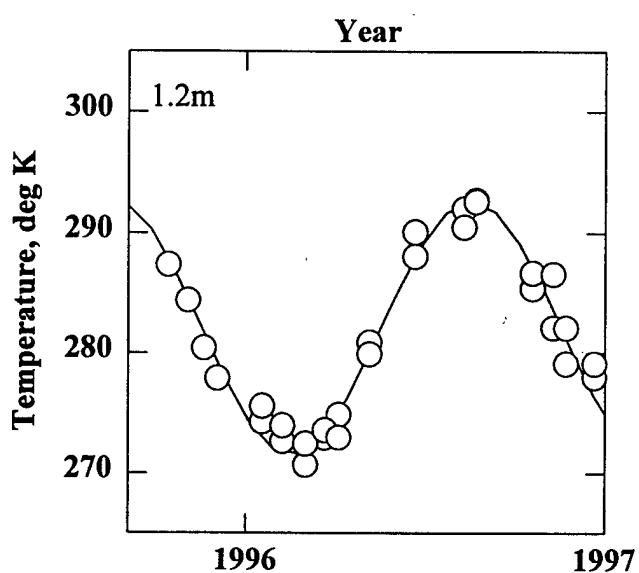
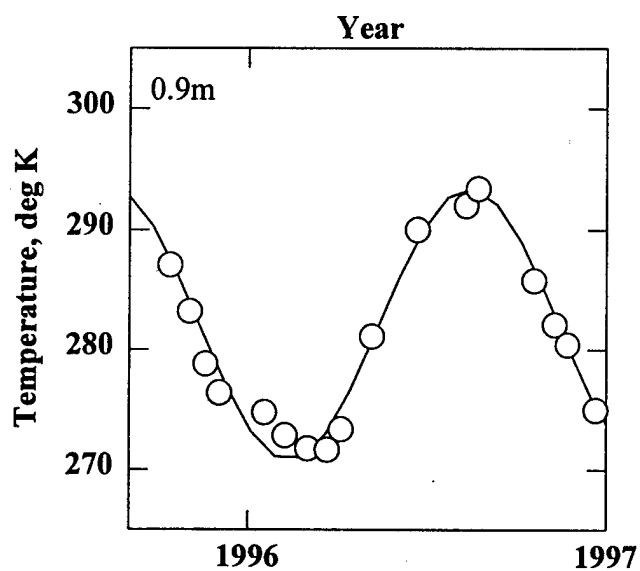
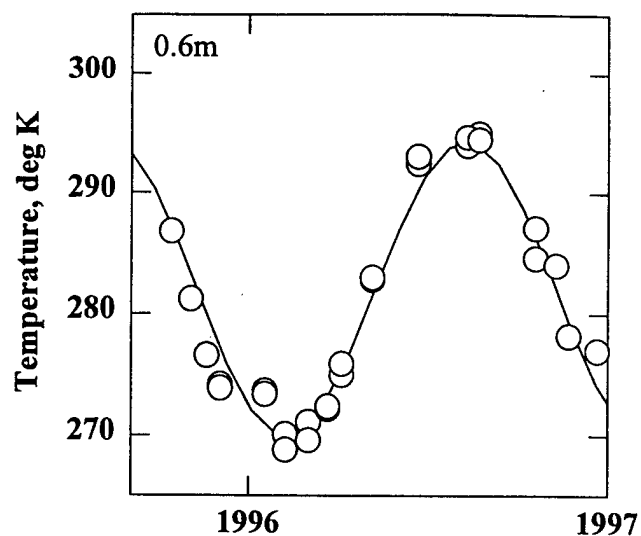
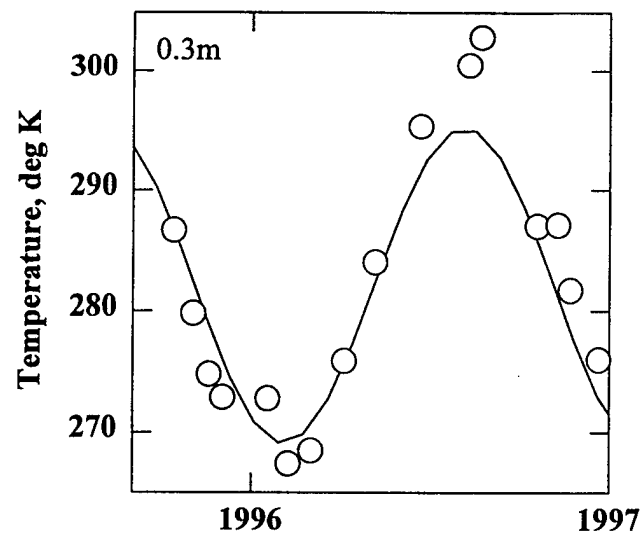


Figure 5.1 Observed (Symbols) and Calibrated (Curves) Soil Temperature

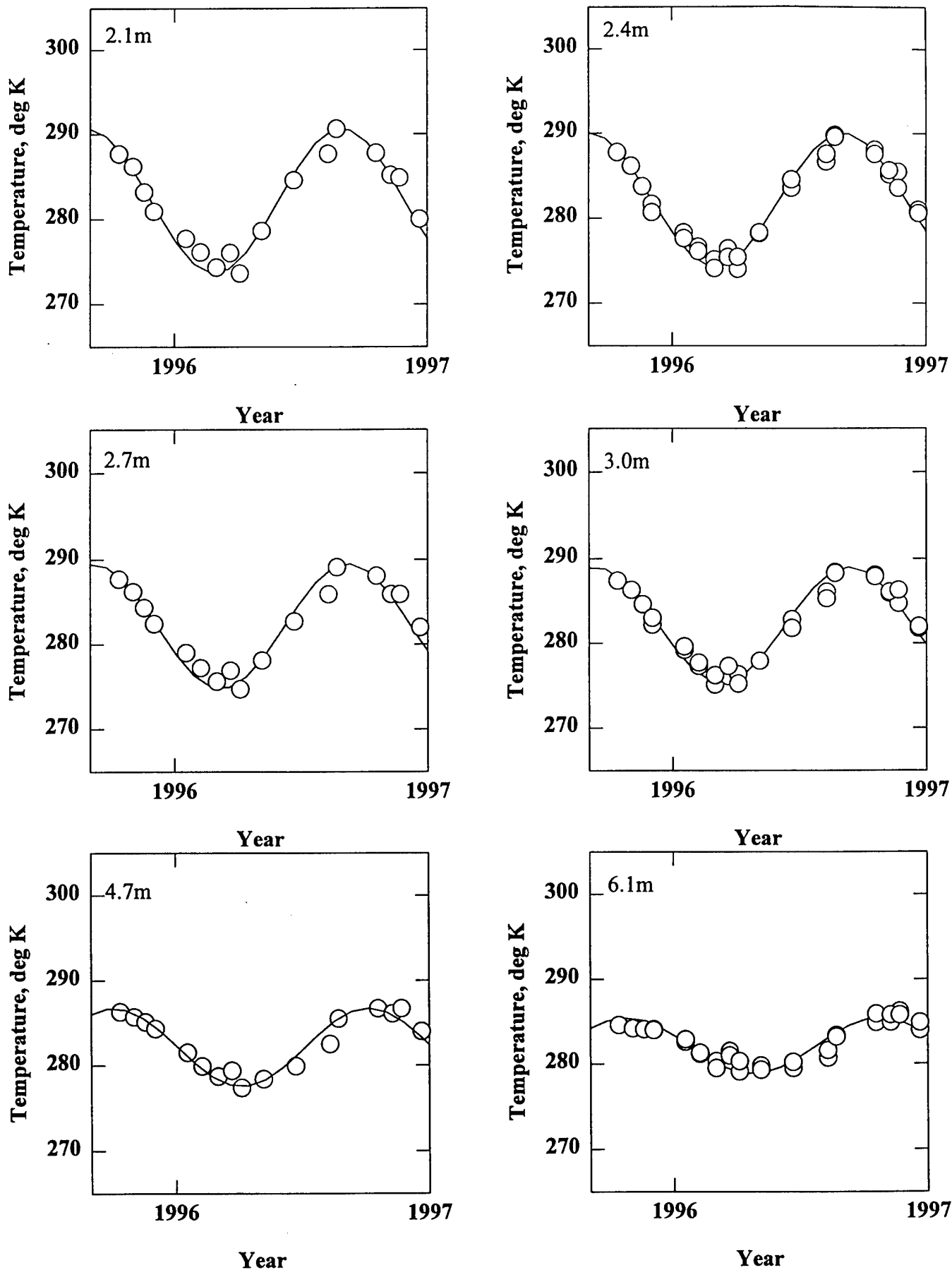


Figure 5.1 (Continued) Observed (Symbols) and Calibrated (Curves) Soil Temperature

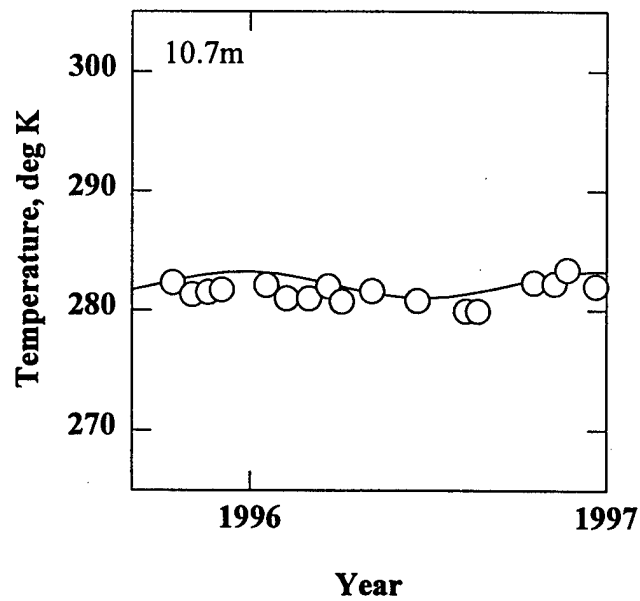
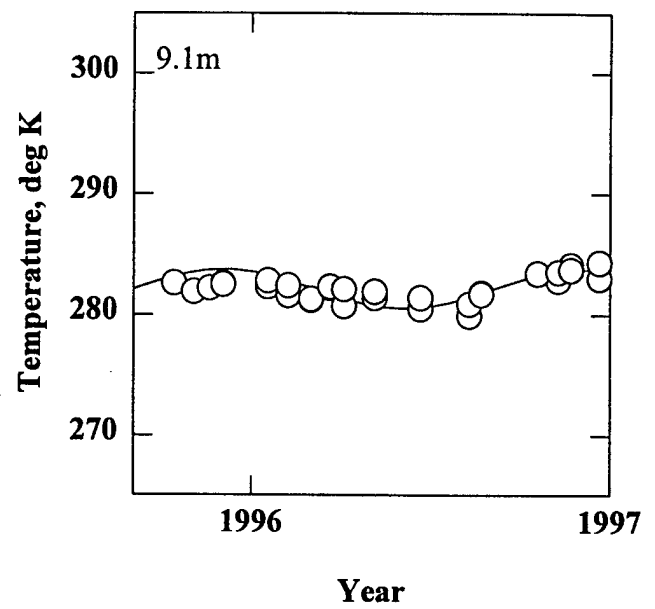
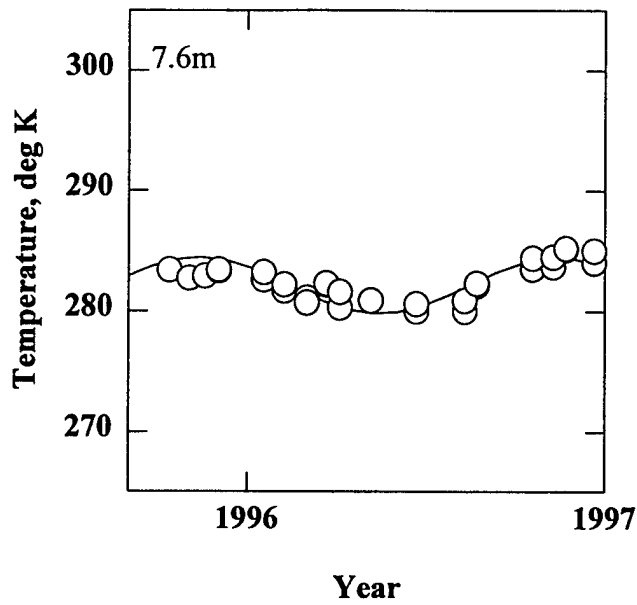


Figure 5.1 (Continued) Observed (Symbols) and Calibrated (Curves) Soil Temperature

$$\delta_D = F(D)\text{measured} - F(D)\text{calibrated} \quad (5.5a)$$

$$\delta_{DM} = \frac{1}{N} \sum_N \delta_D \quad (5.5b)$$

$$\sigma_D = \sqrt{\frac{1}{N} \sum_N \delta_D^2 - \delta_{DM}^2} \quad (5.5c)$$

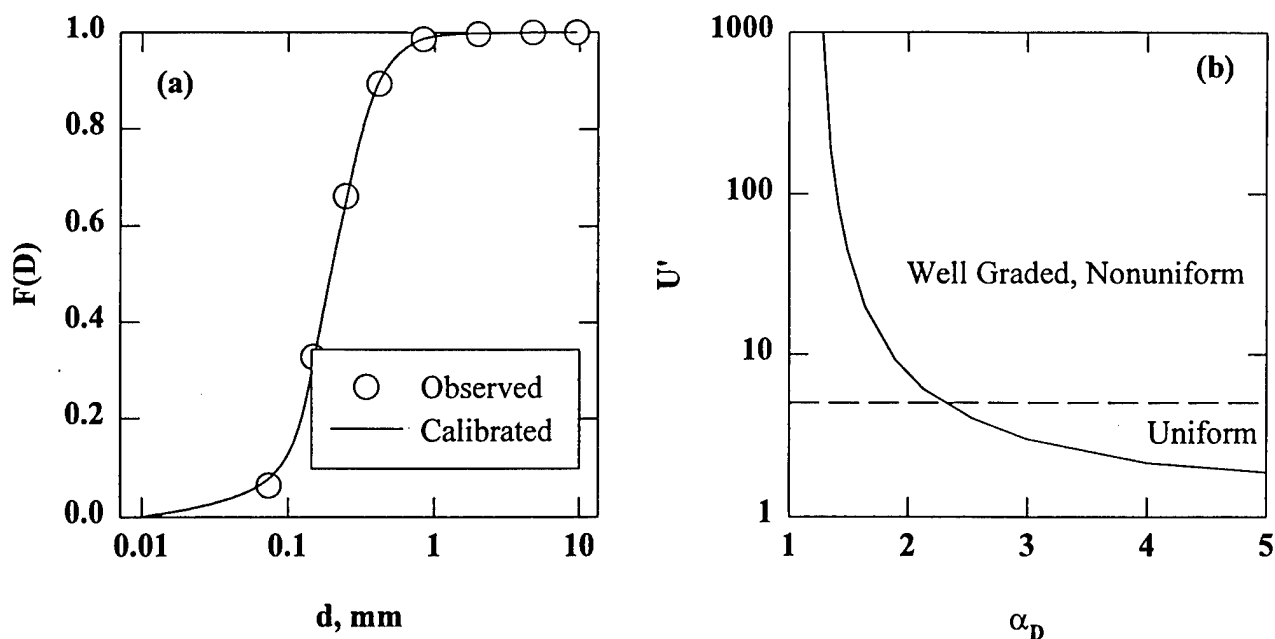


Figure 5.2 (a) Typical Grain Size Distribution Data (Symbols) and Calibration (Curve), (b) Uniformity Coefficient U as a Function of van Genuchten (1980) Uniformity Exponent

Typical calibration results at a particular depth are shown in Figure 5.2a (borehole SPK2, 4.34 m depth). The soil at this location is a medium sand ($d_M=0.24$ mm) with a high uniformity exponent ($\alpha_D=3.16$). In the latter regard, nearly all of the grain sizes are within one order of magnitude in size. Tables 5.3 and 5.4 list the individual calibrations for the depths in each borehole. Figure 5.3a displays the optimal uniformity exponents, which vary from 2.05 to 6.15 in borehole SPK1, 2.22 to 5.00 in borehole SPK2, and 1.56 to 5.58 in borehole 12AY, indicative of highly uniform material. Uniformity coefficients U' are also computed as a conventional measure of particle sorting [Holtz and Kovacs (1981)]

$$U' = \frac{d_{60}}{d_{10}} \quad (5.6a)$$

$$d = d_N \quad [F(D)=N/100] \quad (5.6b)$$

$$U' = \left[\frac{(0.1)^{\frac{\alpha_D}{1-\alpha_D}} - 1}{(0.6)^{\frac{\alpha_D}{1-\alpha_D}} - 1} \right]^{\frac{1}{\alpha_D}} \quad (5.6c)$$

Equation 5.6c, which follows from Equations 5.4a and 5.6a, suggests that α_D and U are inversely related, as indicated by Figure 5.2b. Uniform (poorly graded) soils have U values less than 5 in

**TABLE 5.3 VAN GENUCHTEN (1980) GRAIN SIZE CALIBRATION PARAMETERS
BOREHOLE SPK1**

| Depth, m | d_M , mm | α_D | σ_D , % | U' | F _{FINE} , % |
|----------|------------|------------|----------------|-----|-----------------------|
| 0.23 | 0.47 | 3.47 | 3.1 | 2.5 | 4 |
| 0.69 | 0.79 | 2.65 | 4.5 | 3.6 | 3 |
| 1.14 | 0.92 | 2.43 | 7.6 | 4.3 | 3 |
| 1.60 | 1.59 | 2.05 | 5.7 | 6.8 | 3 |
| 2.06 | 0.57 | 3.41 | 1.9 | 2.5 | 1 |
| 2.52 | 0.56 | 3.21 | 3.7 | 2.7 | 2 |
| 2.97 | 0.55 | 3.19 | 1.4 | 2.7 | 2 |
| 3.43 | 0.58 | 2.92 | 1.8 | 3.1 | 3 |
| 3.89 | 0.38 | 2.69 | 1.1 | 3.6 | 8 |
| 4.34 | 0.42 | 2.75 | 0.7 | 3.4 | 6 |
| 4.80 | 0.31 | 2.15 | 1.2 | 5.9 | 17 |
| 5.26 | 0.28 | 3.06 | 1.1 | 2.9 | 6 |
| 5.72 | 0.21 | 3.63 | 3.0 | 2.4 | 7 |
| 6.17 | 0.16 | 3.44 | 1.7 | 2.5 | 14 |
| 6.63 | 0.15 | 6.15 | 5.6 | 1.6 | 15 |
| 7.09 | 0.23 | 4.07 | 2.5 | 2.1 | 7 |
| 7.55 | 0.23 | 4.49 | 2.4 | 1.9 | 5 |
| 8.00 | 0.16 | 2.93 | 1.6 | 3.1 | 22 |
| 8.46 | 0.14 | 4.13 | 1.5 | 2.1 | 12 |
| 8.92 | 0.19 | 4.10 | 2.1 | 2.1 | 8 |
| 9.37 | 0.26 | 3.17 | 3.7 | 2.8 | 10 |
| 9.83 | 0.39 | 4.51 | 1.2 | 1.9 | 2 |
| 10.3 | 0.42 | 4.25 | 1.3 | 2.0 | 3 |
| 11.2 | 0.37 | 4.78 | 0.9 | 1.9 | 2 |
| 11.7 | 0.46 | 3.45 | 2.0 | 2.5 | 5 |
| 12.1 | 0.46 | 4.85 | 0.5 | 1.8 | 1 |
| 12.6 | 0.46 | 4.85 | 0.4 | 1.8 | 1 |
| 13.0 | 0.41 | 4.54 | 0.8 | 1.9 | 1 |
| 13.5 | 0.40 | 4.77 | 2.0 | 1.9 | 2 |
| 13.9 | 0.38 | 4.70 | 1.0 | 1.9 | 2 |
| 14.4 | 0.38 | 3.84 | 2.1 | 2.2 | 4 |
| 14.9 | 0.39 | 4.67 | 1.0 | 1.9 | 2 |
| 15.3 | 0.42 | 4.38 | 0.7 | 2.0 | 1 |

magnitude. The U' values listed in Tables 5.2-5.4 suggest that this is the case at Plattsburgh.

Figure 5.3b displays optimal mean grain sizes for the three boreholes. The mean grain size varies from 0.14 to 1.59 mm in borehole SPK1, with an average value of 0.43 mm, corresponding to medium sand. The grain size decreases slightly with depth, a trend that is

**TABLE 5.3 (Continued) VAN GENUCHTEN (1980) GRAIN SIZE CALIBRATION
PARAMETERS BOREHOLE SPK2**

| Depth, m | d_M , mm | α_D | σ_D , % | U' | F_{FINE} , % |
|----------|------------|------------|----------------|-----|----------------|
| 0.23 | 0.48 | 2.97 | 2.0 | 3.0 | 4 |
| 0.69 | 0.63 | 2.37 | 3.4 | 4.6 | 3 |
| 1.14 | 0.57 | 3.07 | 1.1 | 2.9 | 3 |
| 1.60 | 0.47 | 2.75 | 1.4 | 3.4 | 5 |
| 2.06 | 0.49 | 2.72 | 0.4 | 3.5 | 4 |
| 2.52 | 0.44 | 2.65 | 1.2 | 3.6 | 4 |
| 2.97 | 0.36 | 2.22 | 2.8 | 5.4 | 9 |
| 3.43 | 0.28 | 2.65 | 4.1 | 3.6 | 4 |
| 3.89 | 0.28 | 4.84 | 0.6 | 1.8 | 1 |
| 4.34 | 0.24 | 3.16 | 0.8 | 2.8 | 6 |
| 4.80 | 0.24 | 4.04 | 0.9 | 2.1 | 3 |
| 5.26 | 0.16 | 4.83 | 1.2 | 1.8 | 7 |
| 5.72 | 0.14 | 3.48 | 0.8 | 2.5 | 18 |
| 6.17 | 0.13 | 3.65 | 1.1 | 2.3 | 20 |
| 6.63 | 0.19 | 3.92 | 0.5 | 2.2 | 7 |
| 7.09 | 0.26 | 4.88 | 1.4 | 1.8 | 2 |
| 7.55 | 0.12 | 3.86 | 1.3 | 2.2 | 22 |
| 8.00 | 0.16 | 3.37 | 2.6 | 2.6 | 18 |
| 8.46 | 0.14 | 4.15 | 0.7 | 2.1 | 13 |
| 8.92 | 0.22 | 4.20 | 1.2 | 2.1 | 4 |
| 9.37 | 0.23 | 3.75 | 1.9 | 2.3 | 7 |
| 9.83 | 0.43 | 4.01 | 0.8 | 2.1 | 2 |
| 10.3 | 0.42 | 4.84 | 1.1 | 1.8 | 2 |
| 10.8 | 0.63 | 3.20 | 3.2 | 2.7 | 2 |
| 12.1 | 0.43 | 5.00 | 0.6 | 1.8 | 0 |

replicated in SPK2 and 12AY. The mean grain size ranges from 0.12 to 0.63 mm in borehole SPK2, with an average value of 0.33 mm. Borehole 12AY exhibits a d_M varying from 0.12 to 2.12 m in size, with an average value of 0.50 mm. We average all the data to characterize the soil in the site area as a highly uniform, medium sand

$$d_M = 0.441\text{mm} \quad (5.7a)$$

$$\alpha_D = 3.68 \quad (5.7b)$$

The observed fine fractions F_{FINE} are also listed in Tables 5.2-5.4, where

$$F = F_{FINE} \quad (d=0.074 \text{ mm}) \quad (5.8)$$

**TABLE 5.4 VAN GENUCHTEN (1980) GRAIN SIZE CALIBRATION PARAMETERS
BOREHOLE 12AY**

| Depth, m | d_M , mm | α_D | σ_D , % | U | F_{FINE} , % |
|----------|------------|------------|----------------|------|----------------|
| 0.15 | 0.76 | 2.44 | 6.4 | 4.3 | 3 |
| 0.46 | 0.61 | 2.46 | 2.4 | 4.2 | 4 |
| 0.76 | 0.64 | 2.44 | 3.5 | 4.3 | 4 |
| 1.07 | 0.77 | 2.54 | 4.9 | 4.0 | 3 |
| 1.37 | 0.62 | 3.01 | 4.5 | 3.0 | 3 |
| 1.68 | 1.73 | 2.06 | 10.6 | 6.7 | 2 |
| 1.98 | 2.12 | 1.98 | 7.4 | 7.7 | 2 |
| 2.29 | 0.60 | 2.70 | 4.9 | 3.5 | 2 |
| 2.59 | 1.82 | 2.02 | 8.5 | 7.2 | 3 |
| 2.90 | 1.87 | 1.56 | 14.6 | 29 | 5 |
| 3.20 | 0.38 | 4.04 | 1.0 | 2.1 | 2 |
| 3.51 | 0.48 | 3.39 | 0.9 | 2.5 | 3 |
| 3.81 | 0.49 | 3.07 | 0.9 | 2.9 | 4 |
| 4.11 | 0.61 | 3.08 | 0.9 | 2.9 | 2 |
| 4.42 | 0.45 | 3.34 | 0.9 | 2.6 | 3 |
| 4.72 | 0.39 | 3.85 | 0.7 | 2.2 | 2 |
| 5.03 | 0.34 | 3.25 | 2.1 | 2.7 | 6 |
| 5.33 | 0.17 | 2.43 | 0.9 | 4.3 | 27 |
| 5.64 | 0.34 | 3.81 | 2.8 | 2.2 | 2 |
| 5.94 | 0.18 | 3.81 | 1.5 | 2.2 | 7 |
| 6.25 | 0.18 | 3.89 | 1.4 | 2.2 | 8 |
| 6.55 | 0.15 | 3.77 | 1.7 | 2.3 | 11 |
| 6.86 | 0.14 | 3.20 | 1.7 | 2.7 | 20 |
| 7.16 | 0.17 | 5.58 | 3.4 | 1.7 | 7 |
| 7.47 | 0.22 | 4.97 | 2.2 | 1.8 | 5 |
| 7.77 | 0.21 | 3.50 | 1.7 | 2.5 | 9 |
| 8.38 | 0.12 | 2.67 | 3.2 | 3.6 | 30 |
| 8.69 | 0.13 | 3.38 | 0.9 | 2.6 | 23 |
| 8.99 | 0.18 | 3.67 | 1.8 | 2.3 | 12 |
| 9.30 | 0.21 | 4.22 | 2.3 | 2.0 | 5 |
| 9.60 | 0.24 | 3.69 | 2.9 | 2.3 | 8 |
| 9.91 | 0.45 | 4.06 | 0.7 | 2.11 | 2 |
| 10.2 | 0.45 | 4.04 | 1.3 | 2.1 | 3 |
| 10.5 | 0.46 | 3.54 | 1.3 | 2.4 | 3 |
| 10.8 | 0.61 | 3.35 | 5.7 | 2.6 | 2 |
| 11.1 | 0.42 | 3.10 | 1.4 | 2.9 | 5 |
| 11.2 | 0.39 | 4.57 | 1.7 | 1.9 | 3 |
| 11.5 | 0.37 | 4.23 | 1.2 | 2.0 | 3 |
| 11.7 | 0.37 | 4.06 | 2.3 | 2.1 | 5 |
| 11.8 | 0.38 | 4.87 | 0.9 | 1.8 | 2 |

**TABLE 5.4 (Continued) VAN GENUCHTEN (1980) GRAIN SIZE CALIBRATION
PARAMETERS BOREHOLE 12AY**

| Depth, m | d _M , mm | α _D | σ _D , % | U' | F _{FINE} , % |
|----------|---------------------|----------------|--------------------|-----|-----------------------|
| 12.0 | 0.43 | 4.74 | 0.8 | 1.9 | 1 |
| 12.1 | 0.44 | 5.07 | 0.3 | 1.8 | 1 |
| 12.2 | 0.41 | 4.86 | 1.0 | 1.8 | 1 |
| 12.4 | 0.42 | 4.15 | 1.3 | 2.1 | 3 |
| 12.6 | 0.43 | 4.67 | 0.4 | 1.9 | 1 |
| 12.8 | 0.38 | 4.89 | 0.7 | 1.8 | 1 |
| 13.0 | 0.37 | 4.83 | 1.0 | 1.8 | 2 |
| 13.2 | 0.38 | 4.90 | 0.6 | 1.8 | 1 |
| 13.4 | 0.36 | 4.98 | 0.6 | 1.8 | 1 |
| 13.6 | 0.36 | 4.70 | 0.9 | 1.9 | 2 |

The fine fractions are also sketched in Figure 5.3c. The sand is generally clean above the 5 m depth and below the 10 m depth, with an appreciable fine fraction in between. In the latter regard, we observe F_{FINE} values as high as 22% in the 5-10 m interval in boreholes SPK1 and SPK2. The fine fraction is as high as 30% at the 8.38 m depth in borehole 12AY.

We list the raw grain size data in Appendix III.

5.1.3 Moisture Content and Porosity

Figure 5.4 displays the mass based moisture content M observed in conjunction with solid core sampling from 24 boreholes throughout the study area. We can infer the volumetric based moisture content θ_w from M when the porosity n is known

$$\theta_w = (1 - n)s_G M \quad (s_G=2.65) \quad (5.9a)$$

$$\theta_w = \frac{\text{moisture} \cdot \text{volume}}{\text{total} \cdot \text{volume}} \quad (5.9b)$$

$$n = \frac{\text{void} \cdot \text{volume}}{\text{total} \cdot \text{volume}} \quad (5.9c)$$

with soil specific gravity s_G. We estimate the total porosity n from measured values of the soil moisture content of saturated soil samples

$$n = \left(\frac{1}{s_G M} + 1 \right)^{-1} \quad (M \text{ saturated}) \quad (5.10)$$

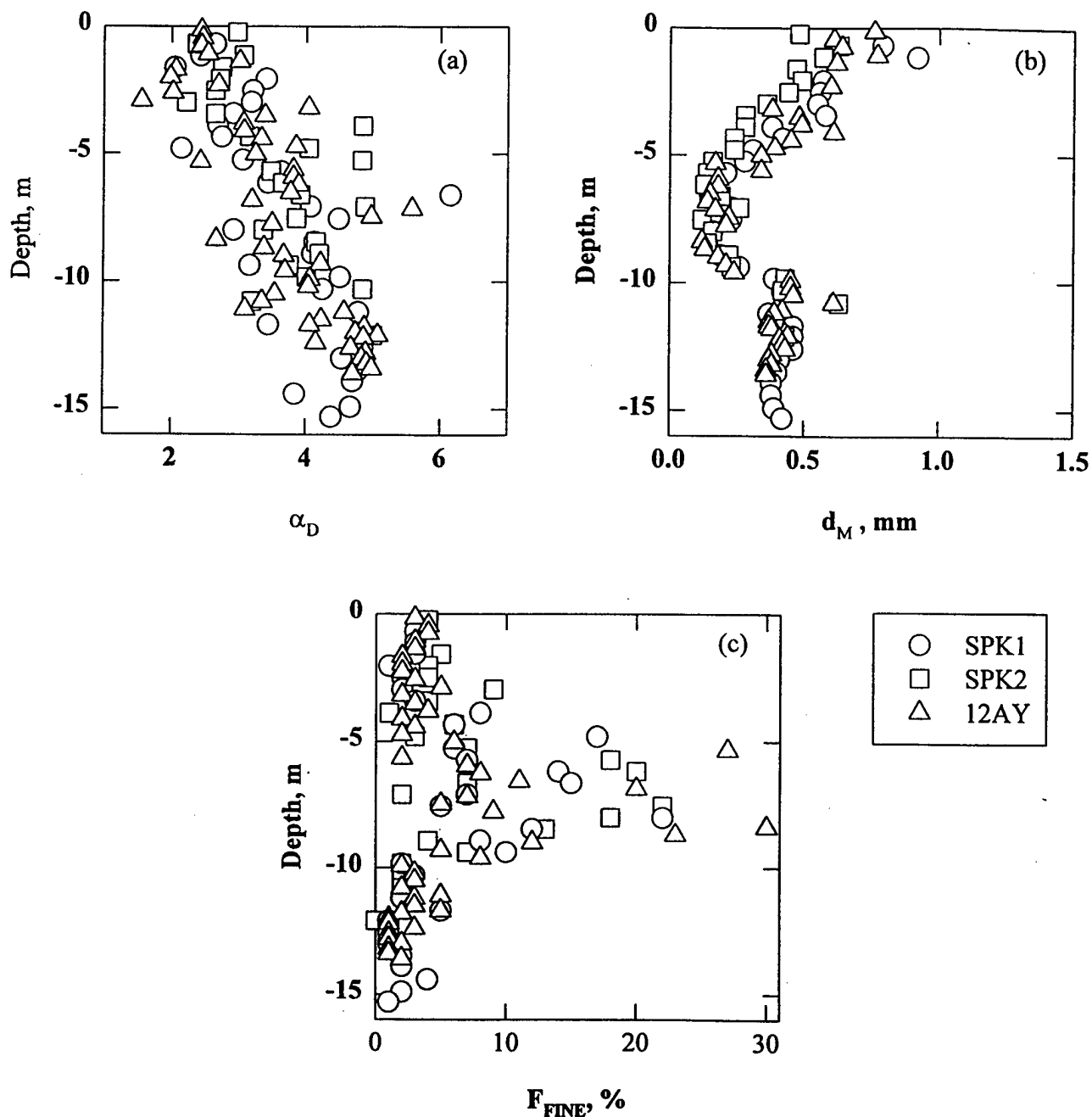
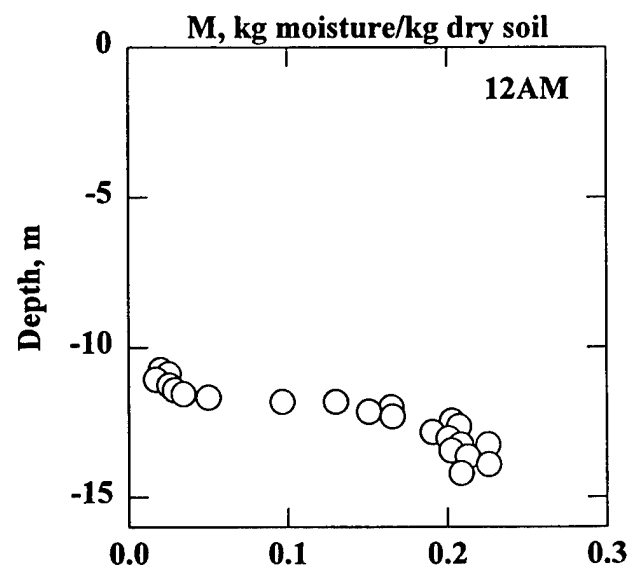
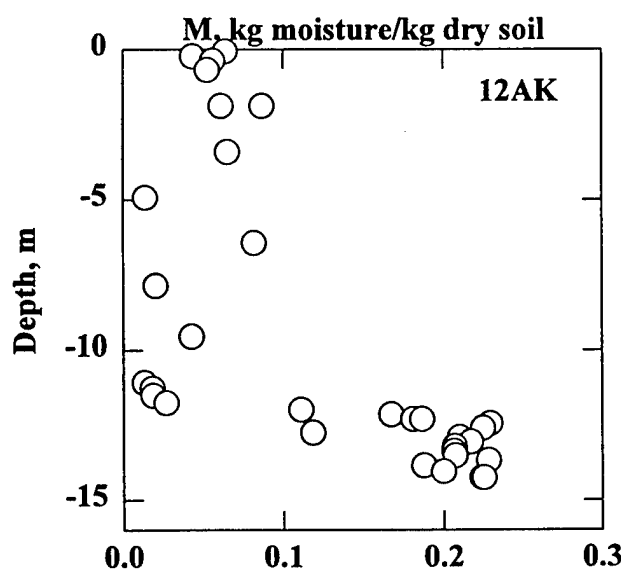
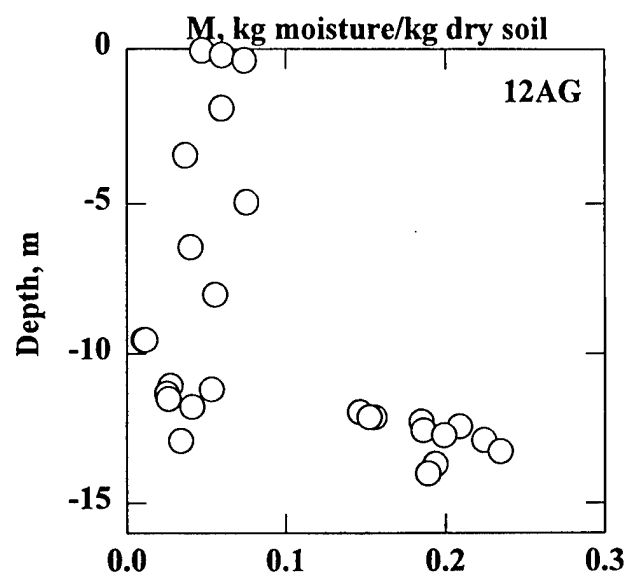
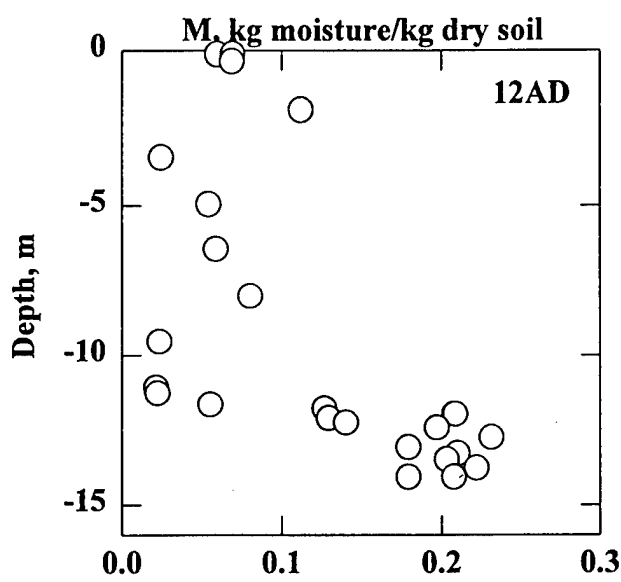
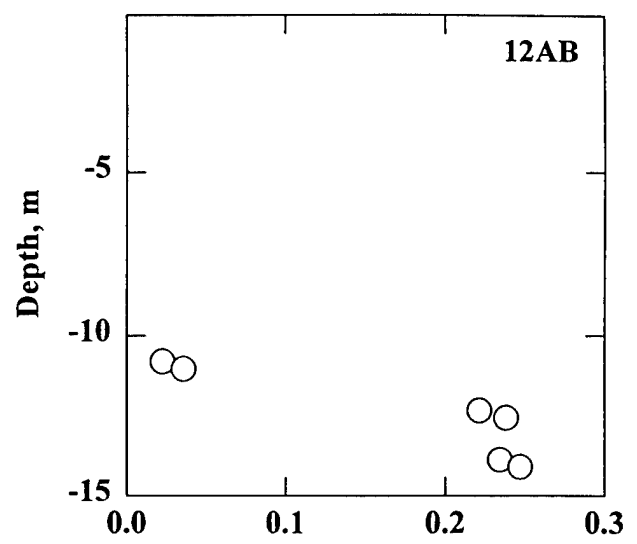
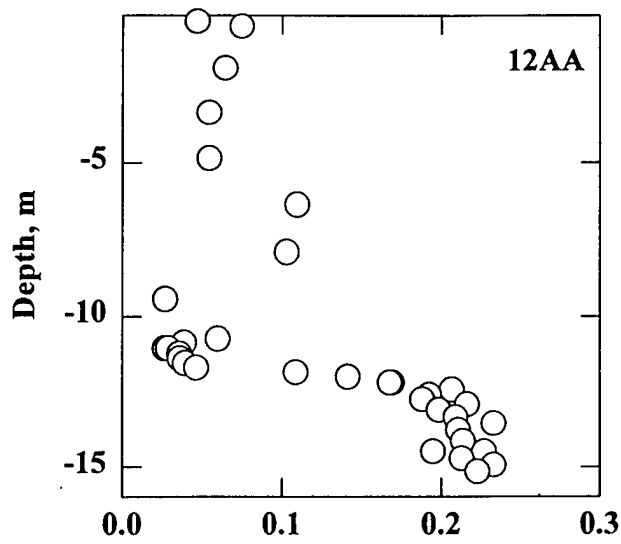


Figure 5.3 Grain Size Calibration Parameters in Boreholes SPK1, SPK2, and 12AY: (a) van Genuchten (1980) Uniformity Exponent, (b) Mean Grain Size, (c) Fine Fraction

We average saturated moisture contents observed in 323 samples taken below the water table from the 24 soil borings shown on Figure 5.4 with the following results

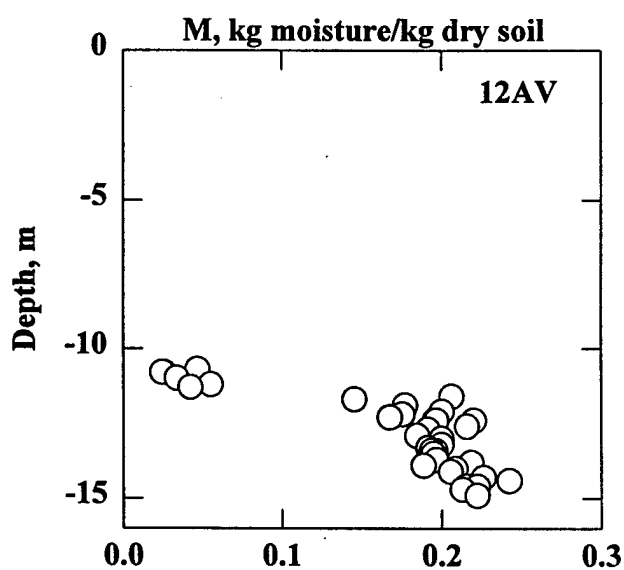
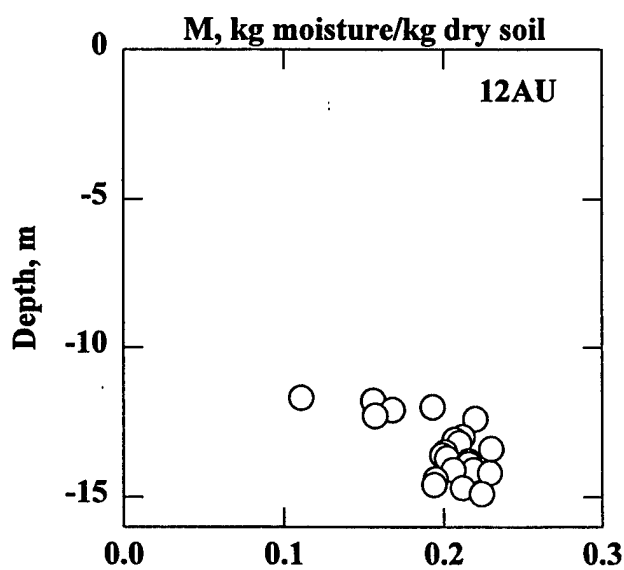
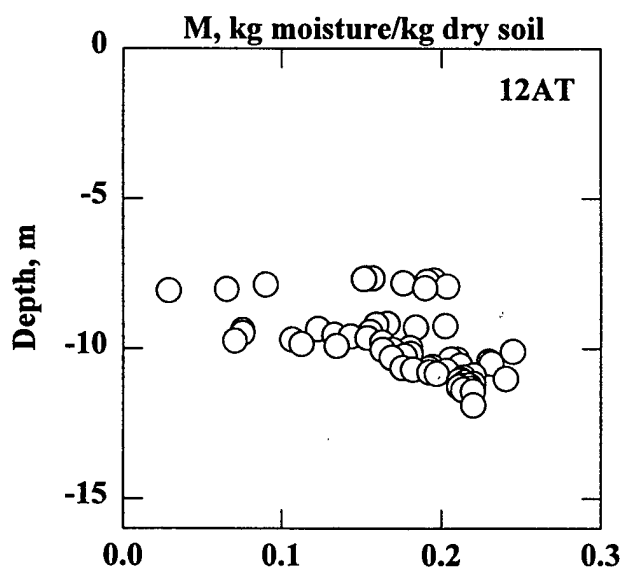
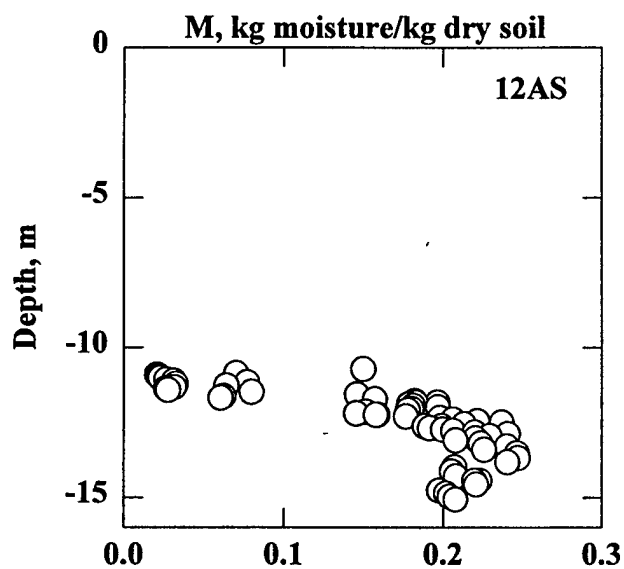
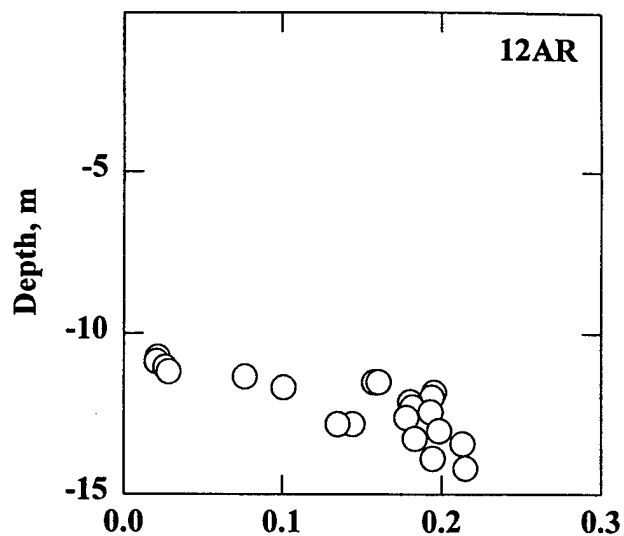
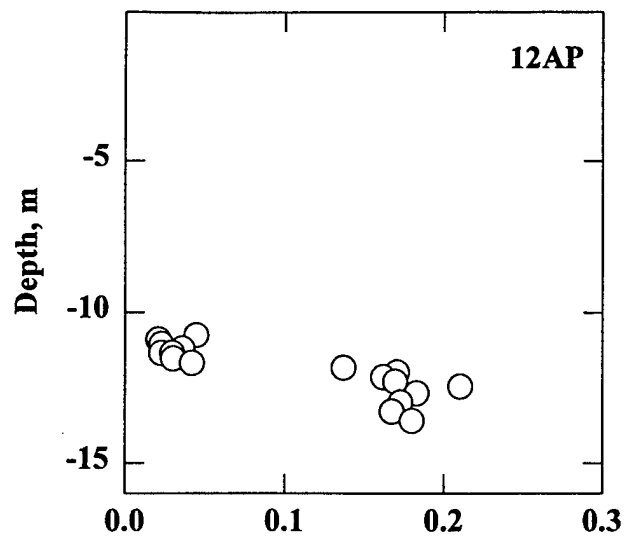
$$M = 0.209 \frac{\text{kg} \cdot \text{moisture}}{\text{kg} \cdot \text{dry} \cdot \text{soil}} \quad (\text{saturated}) \quad (5.11a)$$



M, kg moisture/kg dry soil

M, kg moisture/kg dry soil

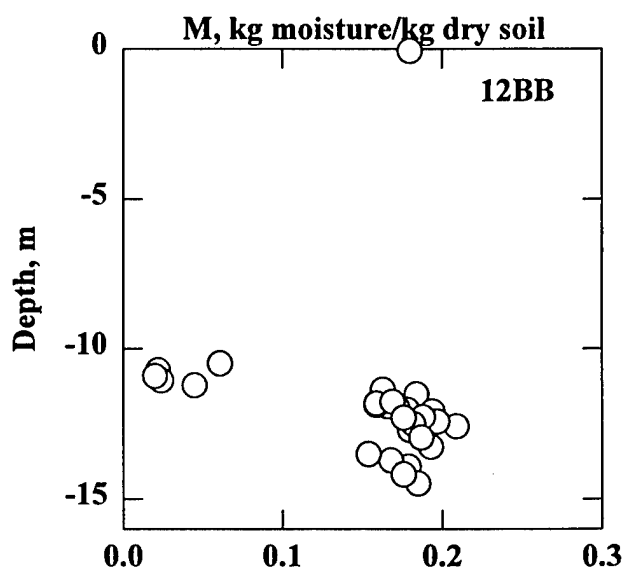
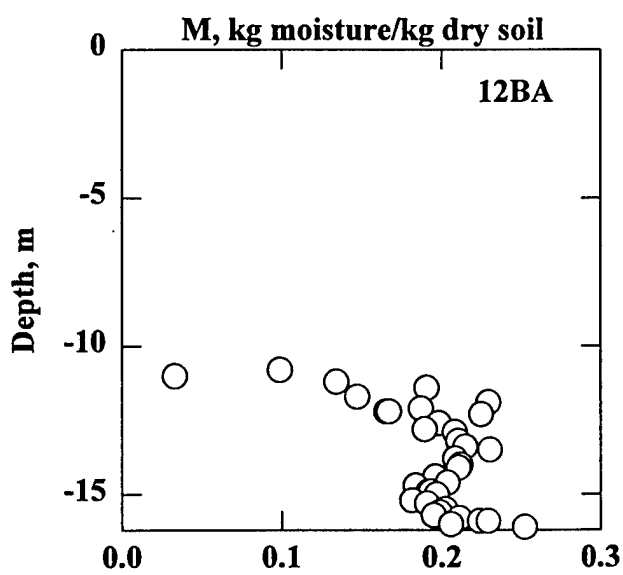
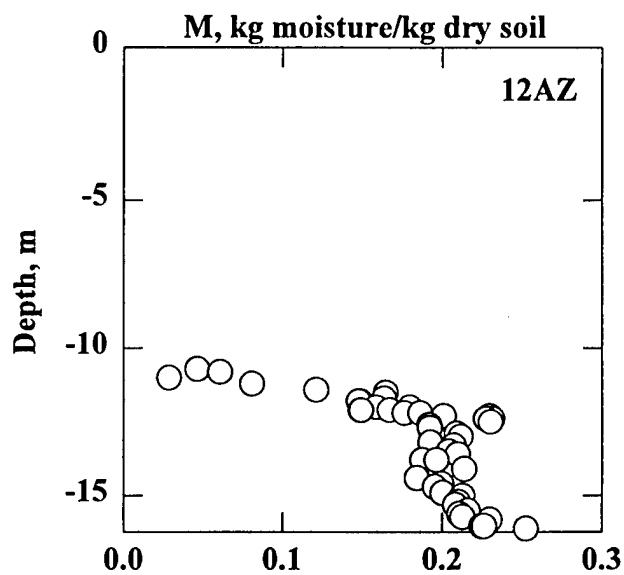
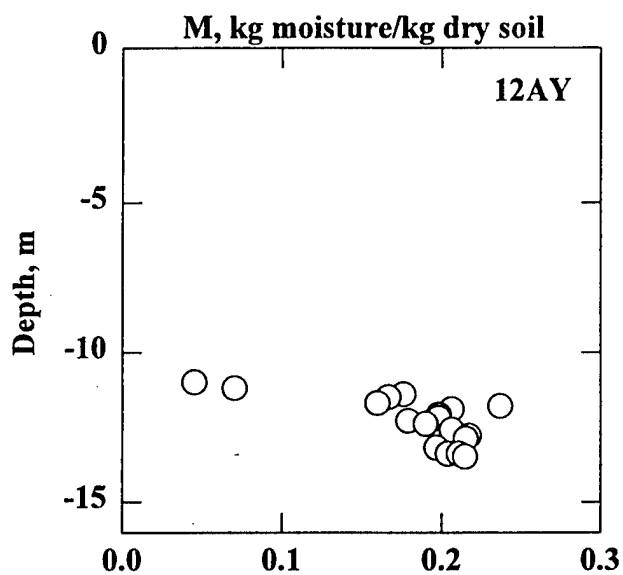
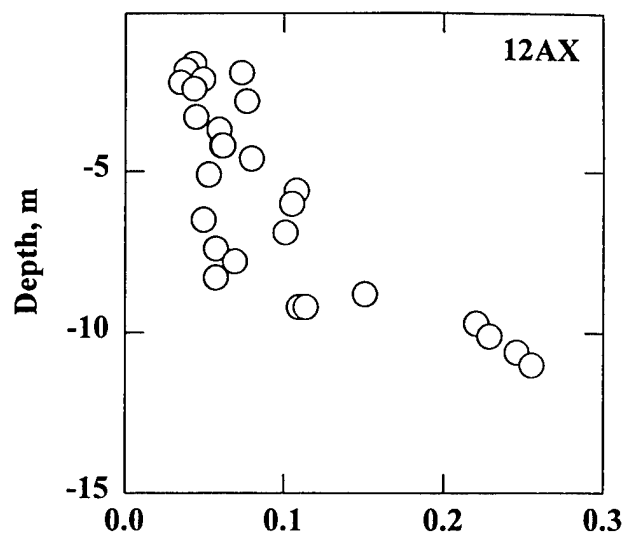
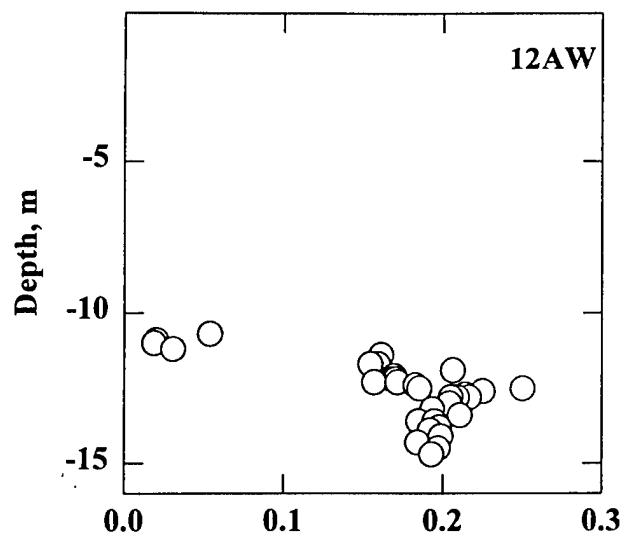
Figure 5.4 Observed Moisture Content in Solid Core Boreholes



M, kg moisture/kg dry soil

M, kg moisture/kg dry soil

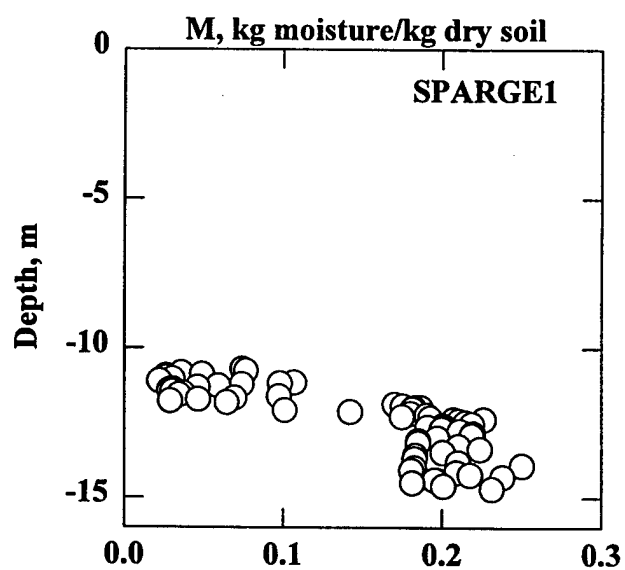
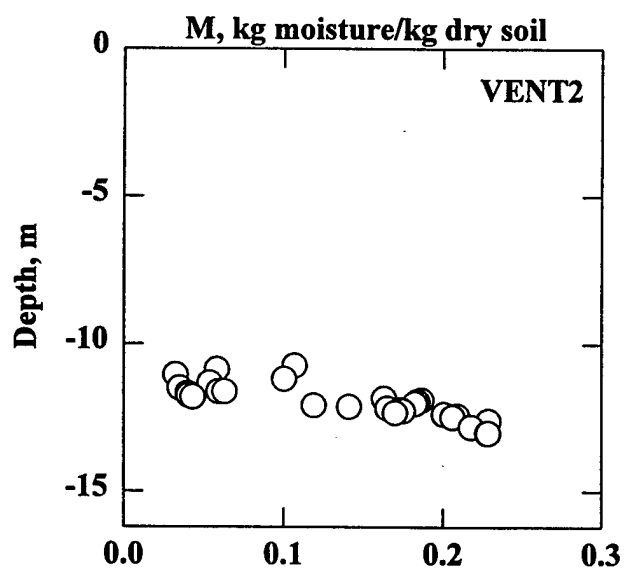
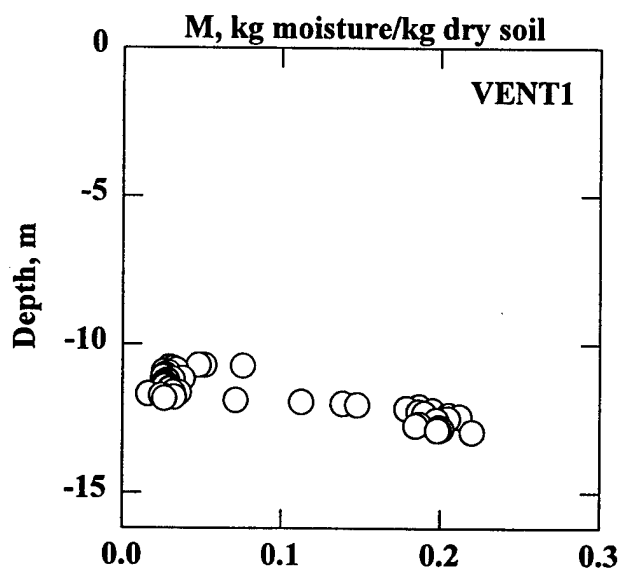
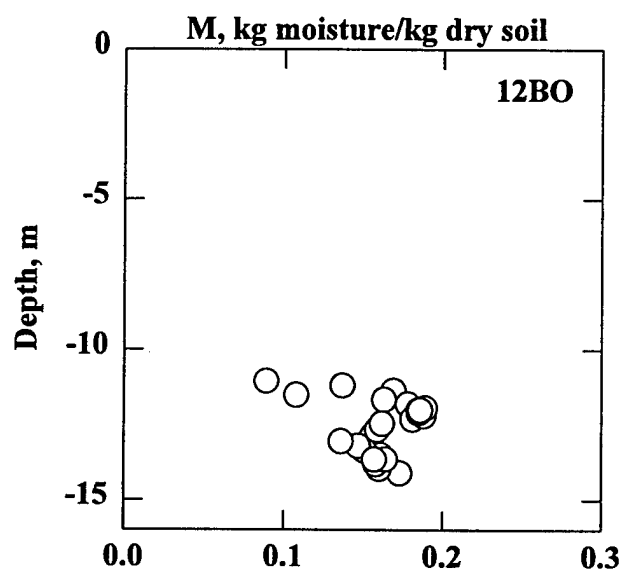
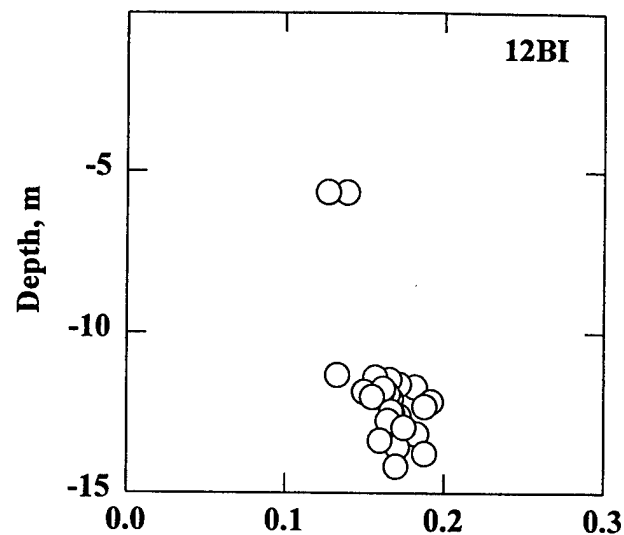
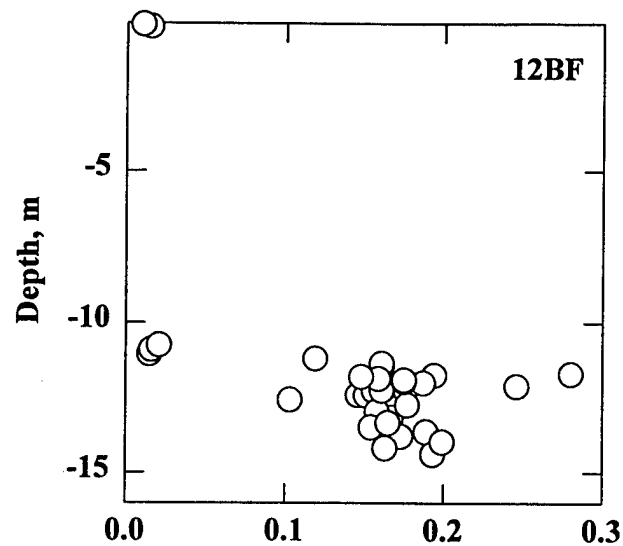
Figure 5.4 (Continued) Observed Moisture Content in Solid Core Boreholes



M, kg moisture/kg dry soil

M, kg moisture/kg dry soil

Figure 5.4 (Continued) Observed Moisture Content in Solid Core Boreholes



M, kg moisture/kg dry soil

M, kg moisture/kg dry soil

Figure 5.4 (Continued) Observed Moisture Content in Solid Core Boreholes

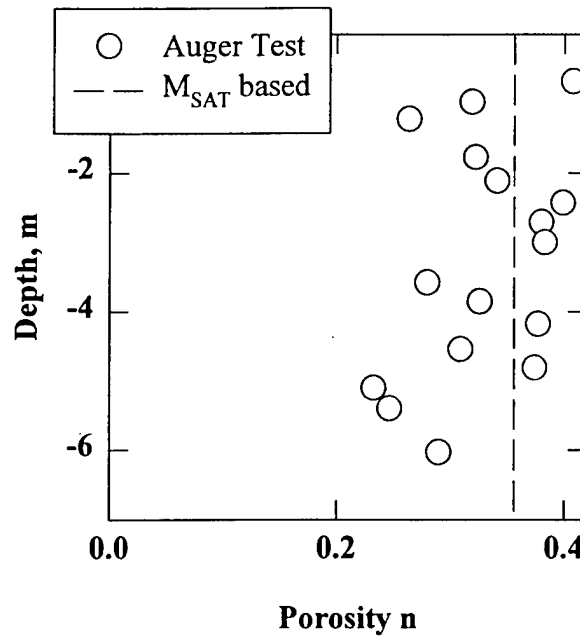


Figure 5.5 Total Porosity, Based on Hand Auger Tests and Saturated Soil Samples

$$n = 0.356 \quad (5.11b)$$

The coefficient of variation of the saturated soil samples is 0.19, corresponding to a reasonably precise estimate of the quantity.

Equation 5.11b compares favorably with the independent porosity estimates inferred from the hand auger data from borehole 12XX. Figure 5.5 plots 16 values observed by weighing known volumes of soil from the borehole--their average of 0.335 is close to the M_{SAT} based value of 0.356.

The total porosity value and moisture content specify the air porosity θ in accordance with

$$\theta = n - \theta_w \quad (5.12a)$$

$$\theta = n - (1 - n)s_G M \quad (5.12b)$$

$$\theta = \frac{\text{air} \cdot \text{volume}}{\text{total} \cdot \text{volume}} \quad (5.12c)$$

TABLE 5.5 BOREHOLE AVERAGED M AND CALCULATED AIR POROSITIES

| Borehole | Interval, m | Samples | Date | M | θ^a |
|----------|-------------|---------|---------|-------|------------|
| 12AA | 0.2-11.7 | 16 | 9Oct95 | 0.053 | 0.265 |
| 12AB | 10.8-11.0 | 2 | 9Oct95 | 0.030 | 0.305 |
| 12AD | 0.1-11.7 | 12 | 10Oct95 | 0.054 | 0.263 |
| 12AG | 0.1-11.8 | 15 | 10Oct95 | 0.043 | 0.282 |
| 12AK | 0.1-11.7 | 15 | 11Oct95 | 0.044 | 0.281 |
| 12AM | 10.7-11.5 | 6 | 12Oct95 | 0.025 | 0.313 |
| 12AP | 10.8-11.7 | 8 | 12Oct95 | 0.031 | 0.303 |
| 12AR | 10.7-11.2 | 4 | 13Oct95 | 0.024 | 0.315 |
| 12AS | 10.7-11.4 | 13 | 1Dec95 | 0.046 | 0.277 |
| 12AV | 10.7-11.3 | 6 | 5Jun96 | 0.038 | 0.291 |
| 12AW | 10.7-11.2 | 4 | 5Jun96 | 0.031 | 0.303 |
| 12AX | 1.6-8.3 | 20 | 6Jun96 | 0.063 | 0.248 |
| 12AY | 11.0-11.2 | 2 | 6Jun96 | 0.057 | 0.259 |
| 12AZ | 10.7-11.0 | 3 | 7Jun96 | 0.045 | 0.279 |
| 12BB | 10.5-11.2 | 5 | 19Aug96 | 0.034 | 0.298 |
| 12BF | 0.0-11.1 | 5 | 21Aug96 | 0.015 | 0.330 |

^aComputed using Equation 5.12b, based on porosity of 0.356.

We compute borehole averaged air porosities for the unsaturated zone by substituting moisture content data of Figure 5.4 into Equation 5.12b, with the results summarized in Table 5.5. The air porosity varies from 0.25 to 0.33, with a site averaged value given by

$$\theta = 0.288 \quad (5.13)$$

The air porosity and total porosity estimates of Equations 5.11b and 5.13 are used in gaseous transport modeling.

5.2 Solid Core Sampling Results

Figure 5.6 displays the total petroleum hydrocarbon content observed in 26 boreholes drilled over the study period. We calibrate the vertical LNAPL distribution model presented in Section 4.2, then assess the separate phase trichlorethylene content determined in selected profiles. The raw data are included in Appendix IV.

5.2.1 Calibration of LNAPL Profile Model

Equations 4.4 and 4.11 relate the mass based total petroleum hydrocarbon observations to the volume based free and residual LNAPL saturation S_L used in our model

$$S_L = S - S_w + S_{LF} \quad (5.14a)$$

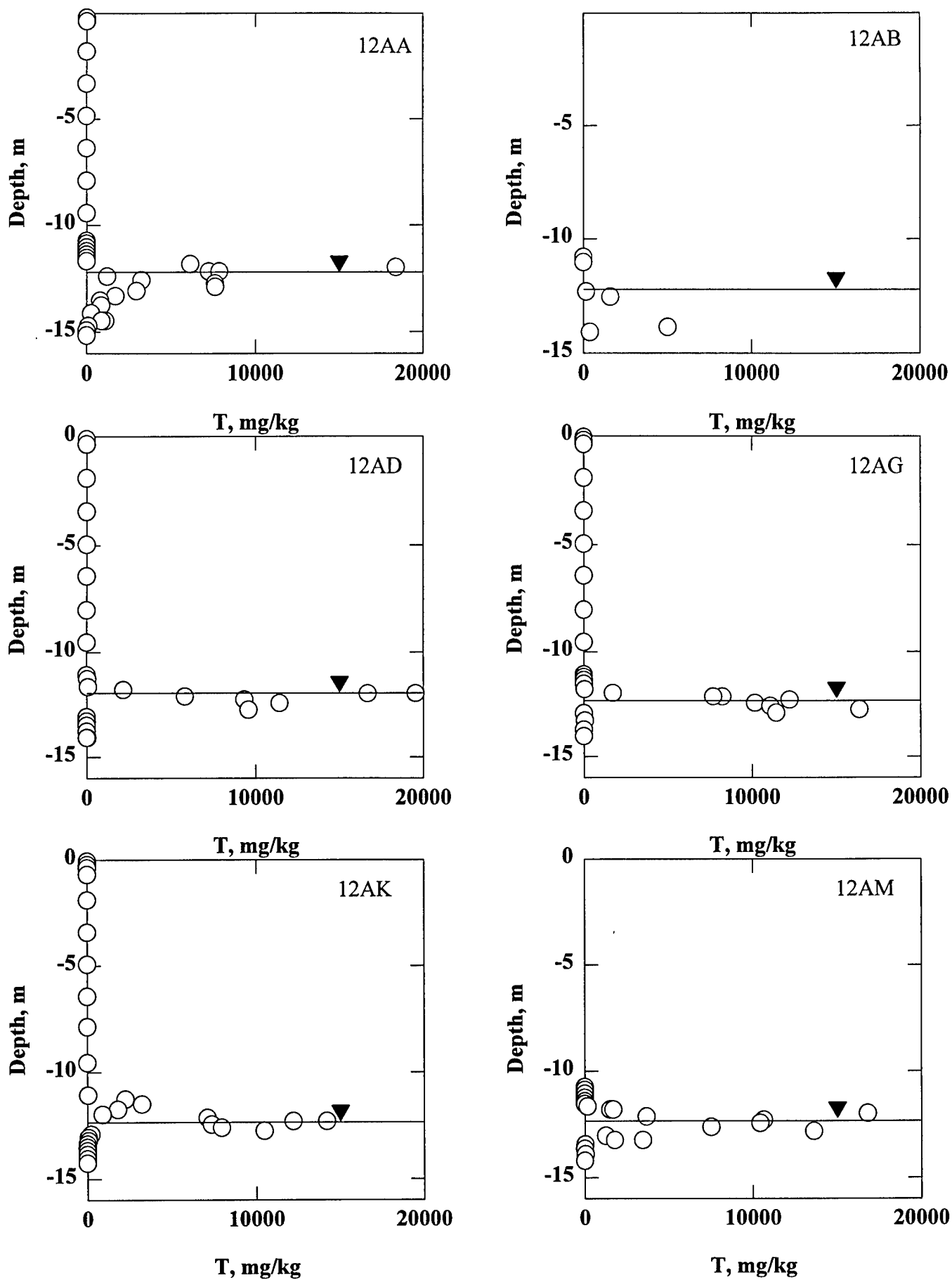


Figure 5.6 Observed Total Petroleum Hydrocarbon Content in Solid Core Boreholes

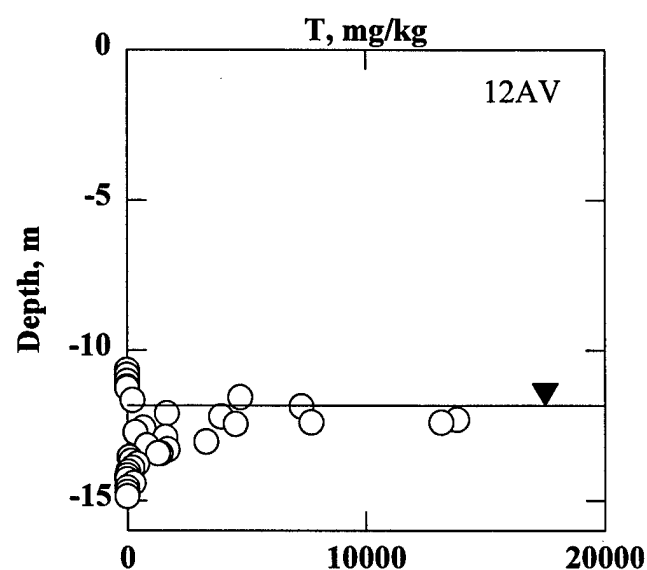
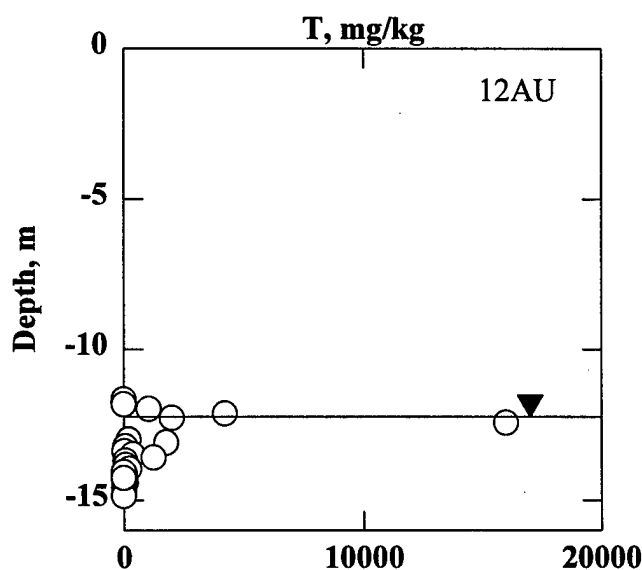
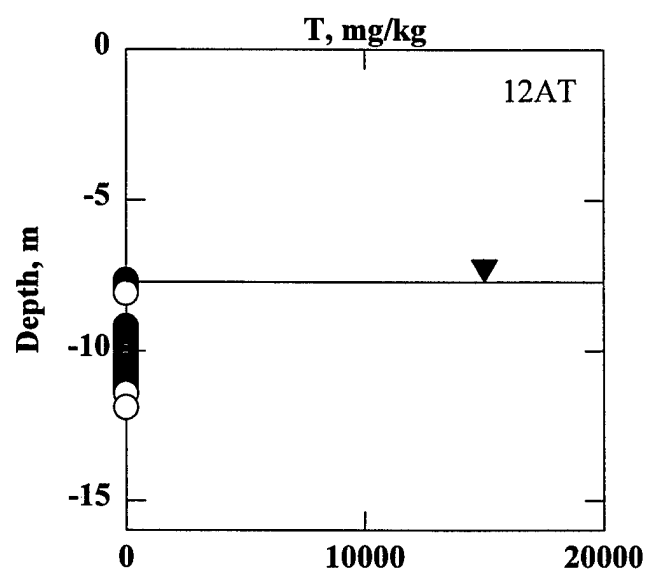
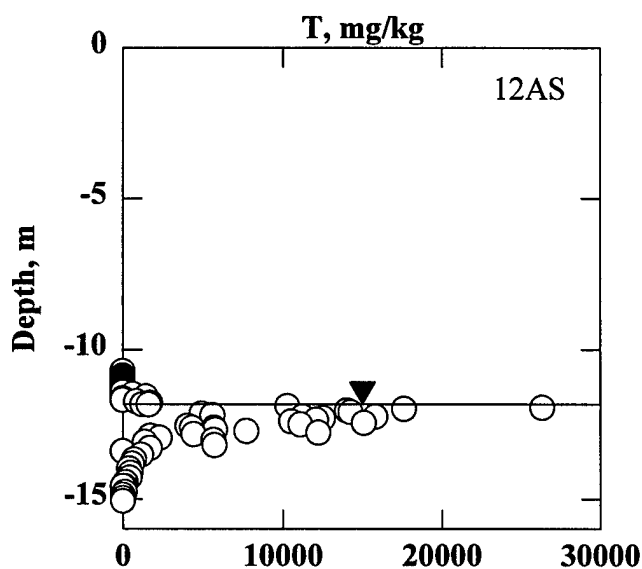
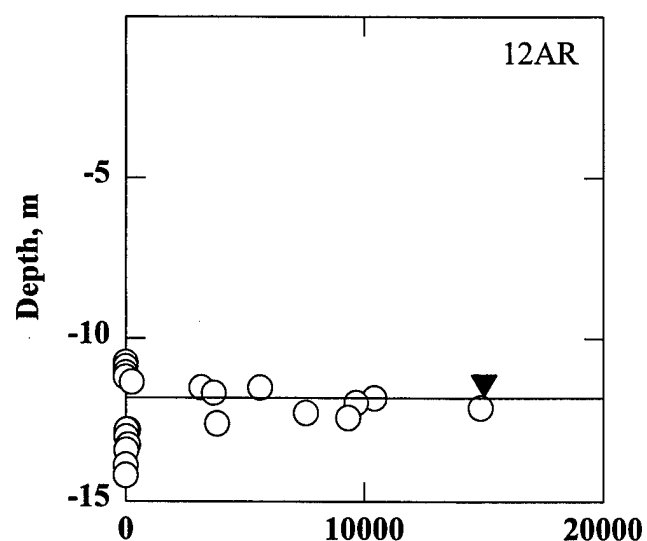
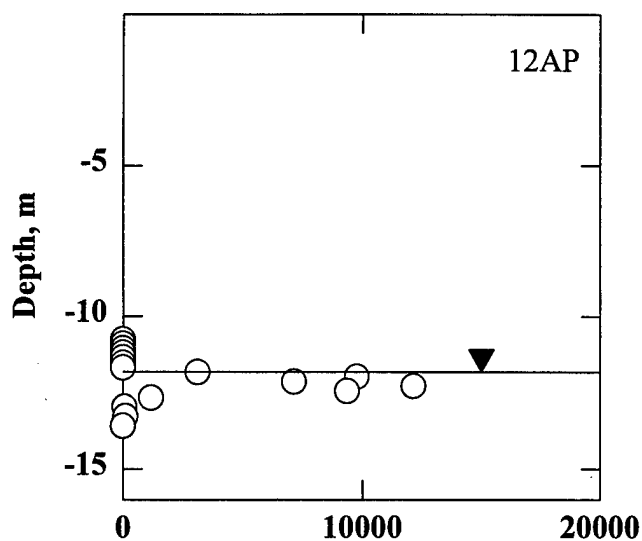


Figure 5.6 (Continued) Observed Total Petroleum Hydrocarbon Content in Solid Core Boreholes

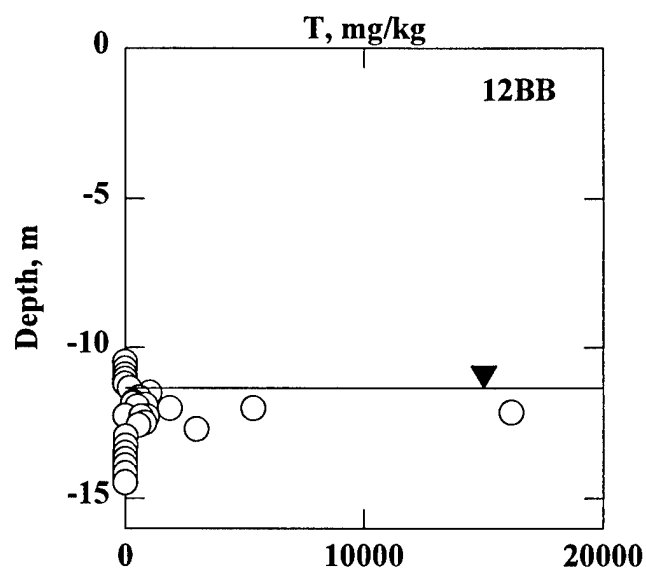
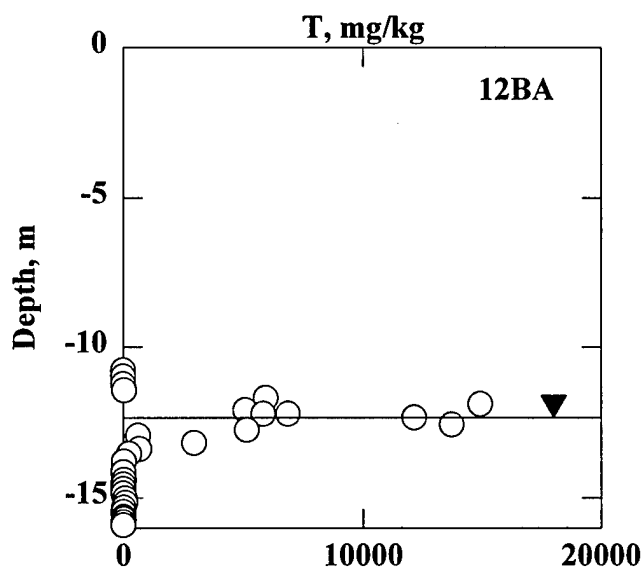
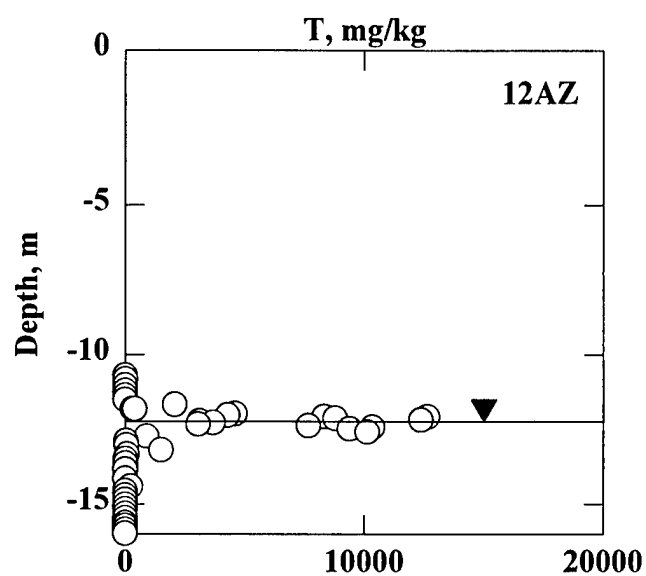
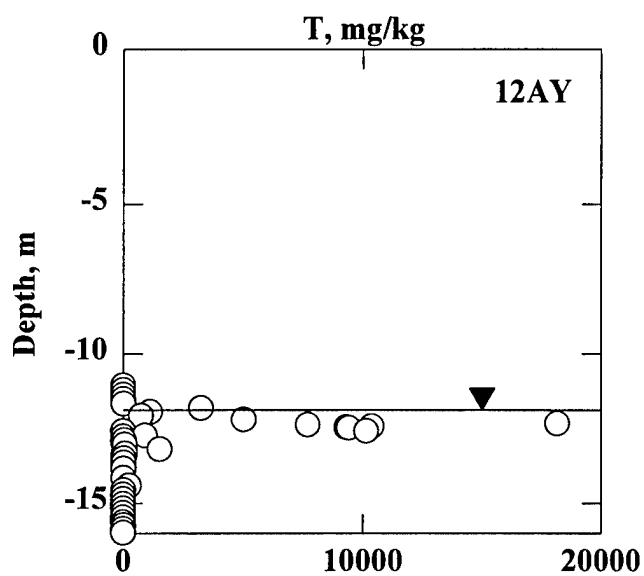
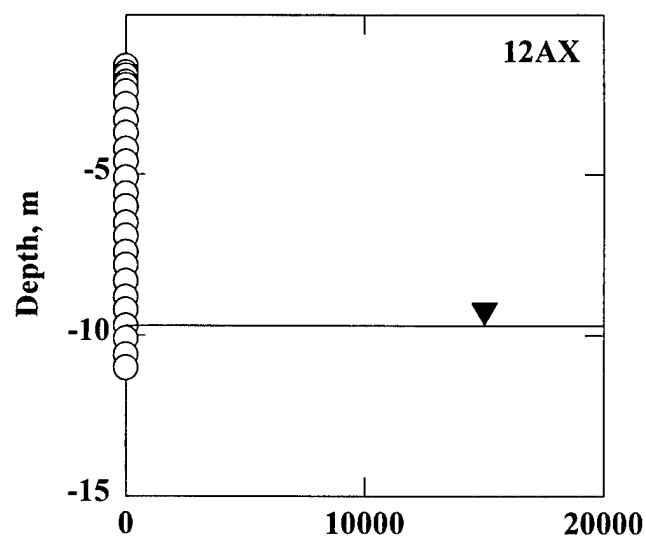
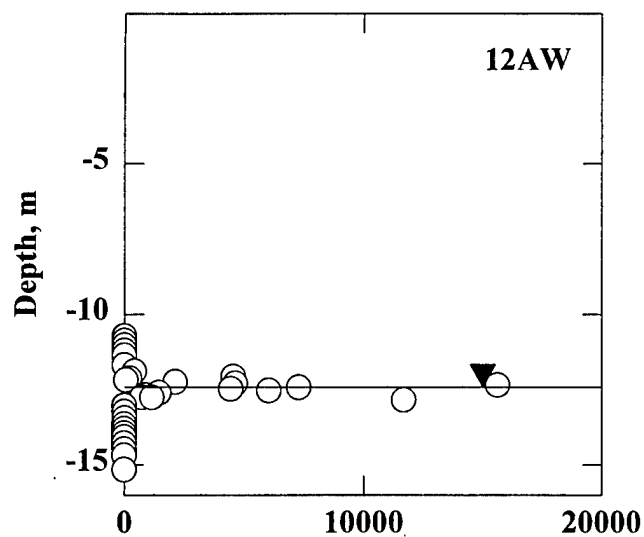


Figure 5.6 (Continued) Observed Total Petroleum Hydrocarbon Content in Solid Core Boreholes

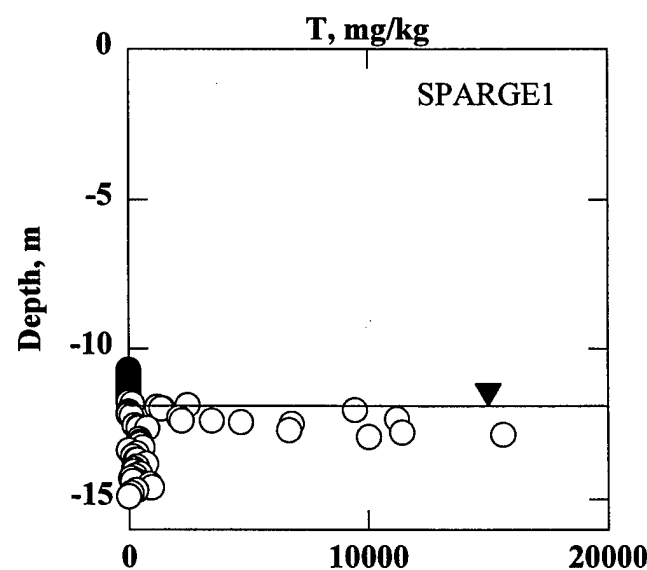
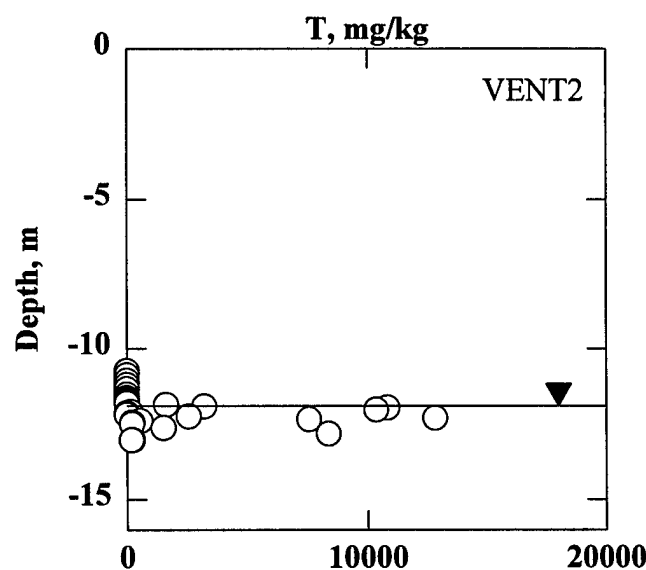
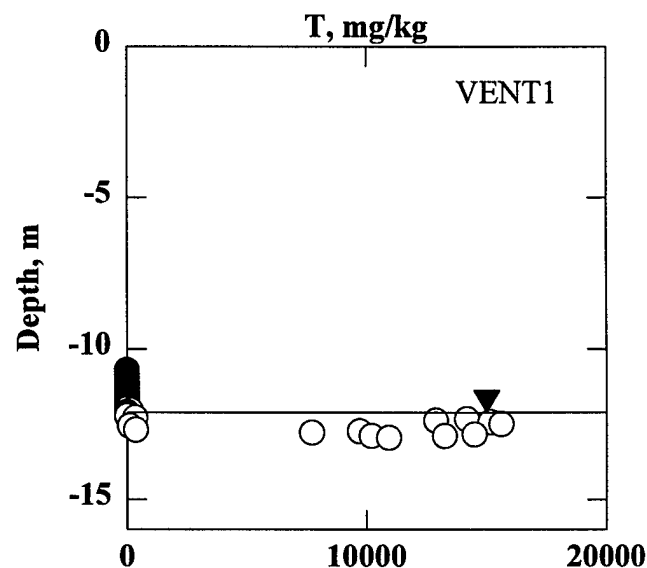
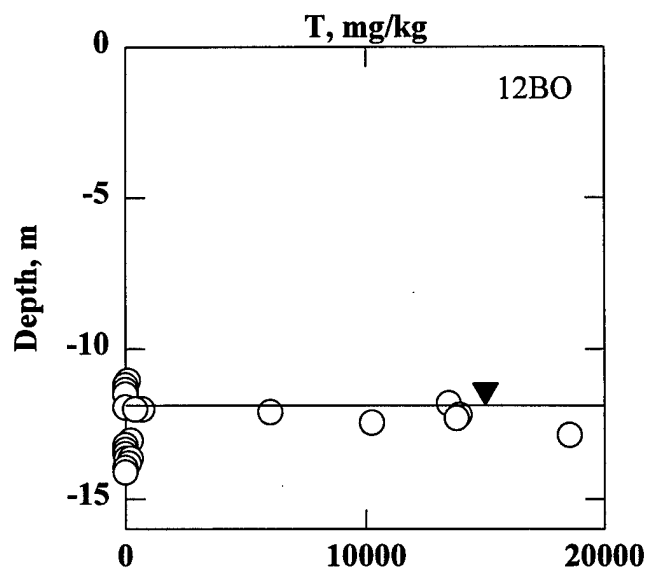
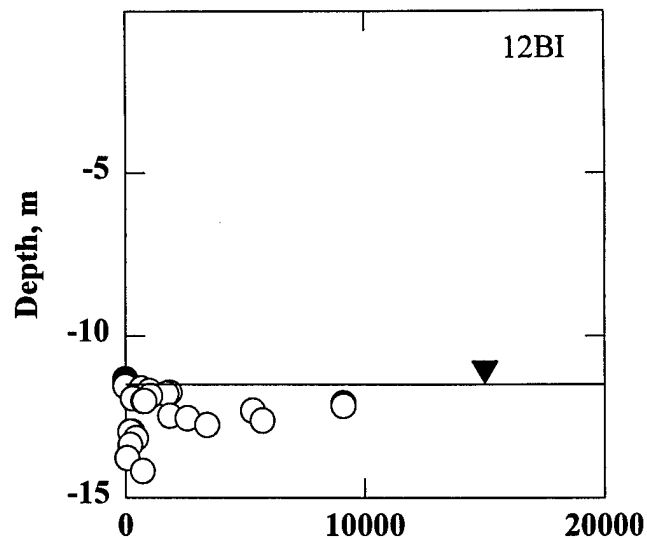
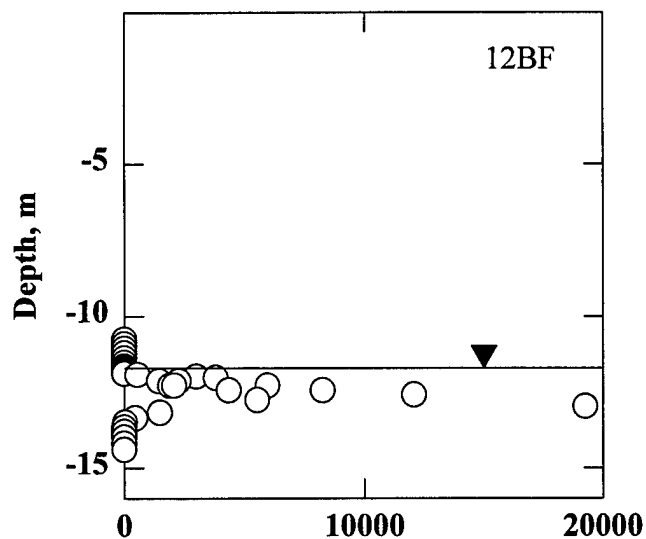


Figure 5.6 (Continued) Observed Total Petroleum Hydrocarbon Content in Solid Core Boreholes

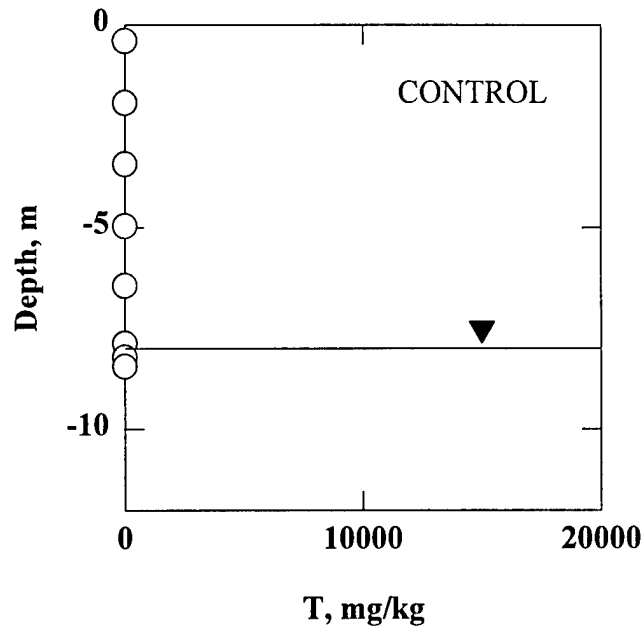


Figure 5.6 (Continued) Observed Total Petroleum Hydrocarbon Content in Solid Core Boreholes

$$S_L = \frac{\rho_B T}{\rho_L (n - \theta_F)} \quad (5.14b)$$

$$S_L = S_{LF} + S_{LR} \quad (5.14c)$$

We obtained a sample of separate phase liquid from a monitoring well near the site area and determined the LNAPL density gravimetrically

$$\rho_L = 830 \frac{\text{kg}}{\text{m}^3} \quad (5.15)$$

while literature values are adopted for surface tensions

$$\sigma_{WA} = 0.074 \frac{\text{N}}{\text{m}} \quad [\text{Streeter and Wylie (1979)}] \quad (5.16a)$$

$$\sigma_{LA} = 0.023 \frac{\text{N}}{\text{m}} \quad [\text{Lenhard and Parker (1990)}] \quad (5.16b)$$

TABLE 5.6 LNAPL PROFILE PARAMETERS AND CALIBRATION RESULTS

| Borehole | ϵ, m^a | $T_{MAX},$ mg/kg^a | α_P | β_L, m^{-1} | $\delta_{SM}, \%$ | $\sigma_S, \%$ |
|----------|-----------------|-------------------------|------------|-------------------|-------------------|----------------|
| 12AA | 1.65 | 18,400 | 6.82 | 10.0 | 0.0 | 15.9 |
| 12AD | 1.82 | 19,500 | 4.84 | 19.8 | 0.0 | 25.6 |
| 12AG | 1.81 | 16,400 | 2.05 | 5.65 | 6.2 | 21.0 |
| 12AK | 1.98 | 14,200 | 6.81 | 7.05 | 0.0 | 20.4 |
| 12AM | 1.95 | 16,800 | 4.40 | 15.2 | 0.0 | 16.3 |
| 12AP | 1.45 | 12,100 | 6.96 | 7.05 | 11.9 | 20.2 |
| 12AR | 2.09 | 14,900 | 3.18 | 7.22 | 0.0 | 25.9 |
| 12AS | 2.54 | 26,400 | 4.03 | 9.78 | 0.0 | 21.5 |
| 12AV | 2.22 | 13,800 | 3.12 | 7.39 | 0.0 | 27.5 |
| 12AW | 1.43 | 15,600 | 3.04 | 7.05 | 0.0 | 28.9 |
| 12AY | 1.10 | 18,200 | 1.76 | 7.05 | 7.0 | 25.9 |
| 12AZ | 2.72 | 12,700 | 3.32 | 7.05 | 0.0 | 24.5 |
| 12BA | 2.11 | 14,900 | 2.05 | 7.77 | 0.3 | 17.2 |
| 12BB | 2.03 | 16,200 | 3.40 | 7.16 | 0.1 | 33.0 |
| 12BF | 1.80 | 19,300 | 3.04 | 7.04 | 29.3 | 43.5 |
| 12BO | 1.62 | 13,900 | 1.67 | 3.34 | 0.5 | 29.6 |
| VENT2 | 1.32 | 12,800 | 3.85 | 7.05 | 0.0 | 28.2 |
| SPARGE1 | 2.05 | 15,600 | 5.38 | 5.06 | 0.0 | 31.0 |

^aObserved.

$$\sigma_{WL} = 0.051 \frac{N}{m} \quad [\text{Lenhard and Parker (1990)}] \quad (5.16c)$$

Groundwater level data cited by the Base engineers [ABB (1993)] suggest a water table fluctuation of

$$\Delta = 1.0m \quad (5.17)$$

in the vicinity of the study area. The core data support a hysteretical trapping factor of 20, which leads to an estimate of the maximum trapped LNAPL by virtue of Eq. 4.13

$$\gamma = 20 \quad (5.18a)$$

$$S_{LRMAX} \cong 0.050 \quad (\gamma \gg 1) \quad (5.18b)$$

We complete the specification of common profile parameters by estimating the irreducible moisture content and the dry soil bulk density. The smallest M value in Table 5.5 (0.015), corresponding to dry conditions, is substituted into Eq. 5.9a to derive a value for θ_F

$$\theta_F = 0.026 \quad (5.19)$$

The total porosity estimate (Eq. 5.11b) implies a ρ_B value

$$\rho_B = s_G(1 - n)\rho \quad (s_G=2.65) \quad (5.20a)$$

$$\rho_B = 1,710 \frac{\text{kg}}{\text{m}^3} \quad (5.20b)$$

The model calibration requires that total and LNAPL saturation data determine the error statistics, since both are described by the same pore size distribution. A nested Fibonacci search is run through the S and S_L data for each borehole, to establish minimal saturation error mean δ_{SM} and standard deviation σ_S . The statistics are defined by the two data sets

$$\delta_{SM} = \frac{1}{2N} \sum [S(\text{observed}) - S(\text{predicted}) + \frac{S_L(\text{observed}) - S_L(\text{predicted})}{0.2}] \quad (5.21a)$$

$$\sigma_S = \sqrt{\frac{1}{2N} \sum \{ [S(\text{observed}) - S(\text{predicted})]^2 + \left[\frac{S_L(\text{observed}) - S_L(\text{predicted})}{0.2} \right]^2 - \delta_{SM}^2} \quad (5.21b)$$

The use of a typical maximum observed LNAPL saturation (0.20) to normalize the LNAPL error contribution places equal weight on the total and LNAPL saturation in determining the error statistics, since S has a maximum value of unity. We optimize the pore size uniformity to zero the mean error and the scaling factor β_L (hence, the mean pore radius) to minimize σ_S for each borehole.

We use an approximate peak concentration matching relation to enforce a relation between the van Genuchten (1980) pore size parameters (α_p, β_L) and the LNAPL and water table depths (b_L, b_w) for the free LNAPL profiles. The maximum observed LNAPL saturation S_{LMAX} and its depth b_{LMAX} are set equal to their observed values, based on data cited in Table 5.6. The matching relations are derived by Ostendorf et al. (1993)

$$b_w = \left\{ \frac{S_{LMAX} - S_{LRMAX}}{(1 - \frac{1}{\alpha_p})[1 - (\frac{\beta_w}{\beta_L})^{\frac{\alpha_p}{\alpha_p-1}}]} \right\}^{\frac{1}{\alpha_p}} \left(\frac{1}{\beta_w} \right) + b_{LMAX} \quad (5.22a)$$

$$b_L = (b_w - b_{LMAX}) \left(\frac{\beta_w}{\beta_L} \right)^{\frac{\alpha_p}{\alpha_p-1}} + b_{LMAX} \quad (5.22b)$$

5.2.2 LNAPL Results

Figure 5.7 and Table 5.6 summarize the LNAPL calibration results for 18 solid core profiles. The pore size uniformity exponent varies between 1.67 and 6.96, while the LNAPL

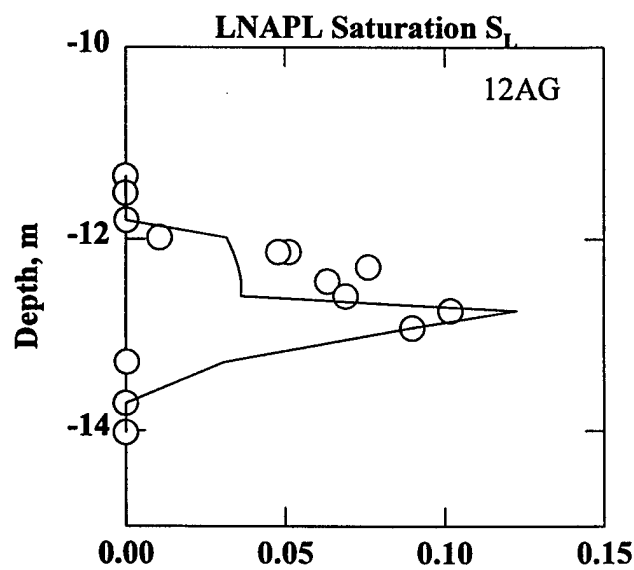
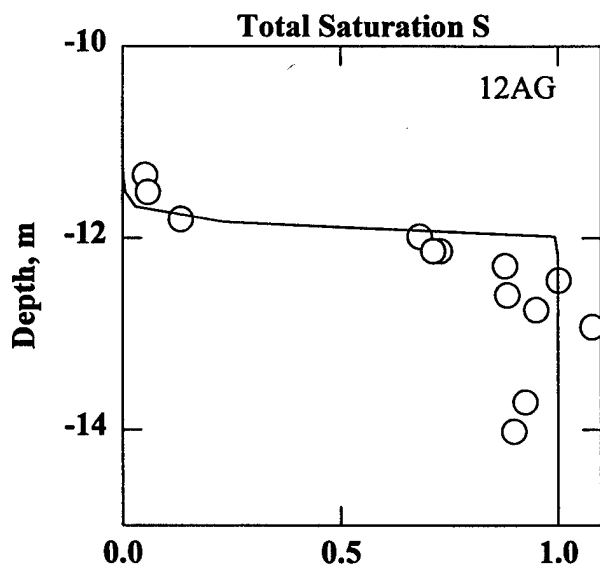
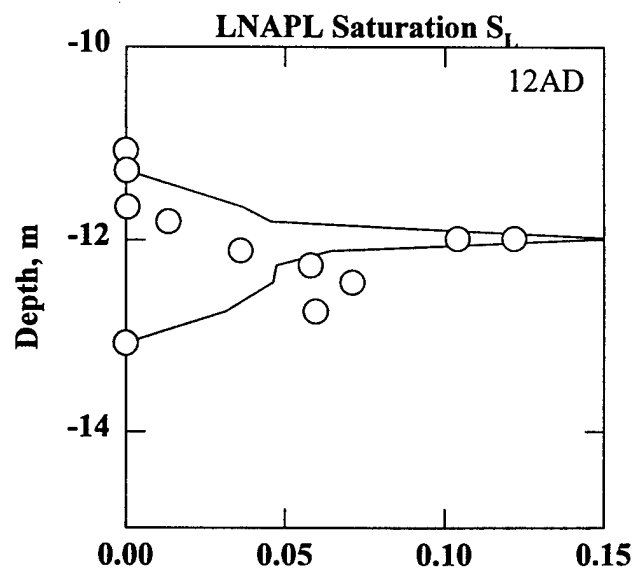
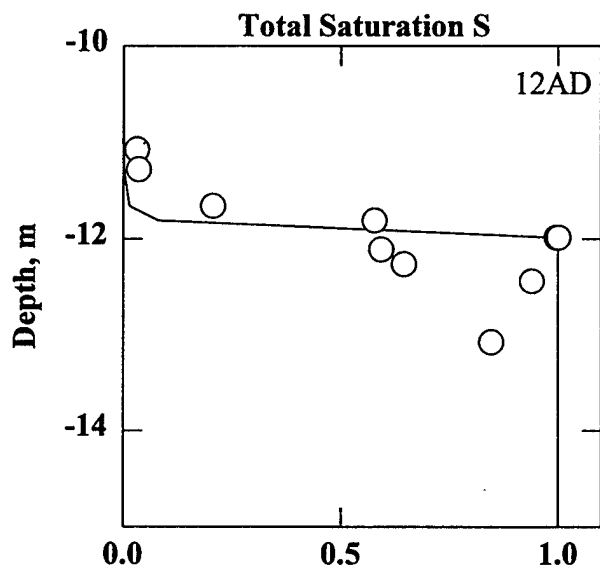
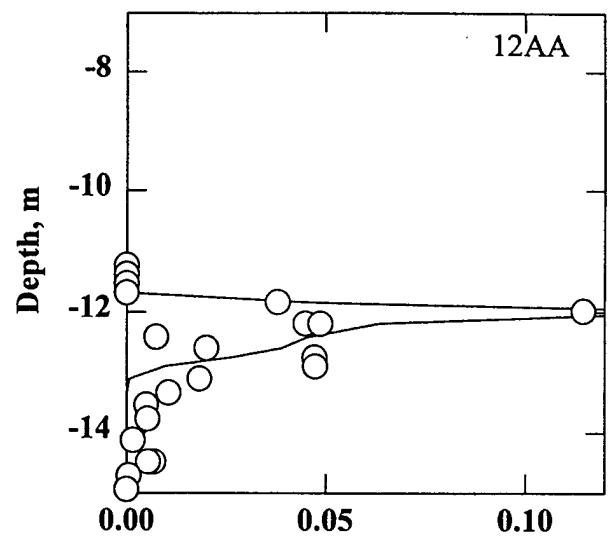
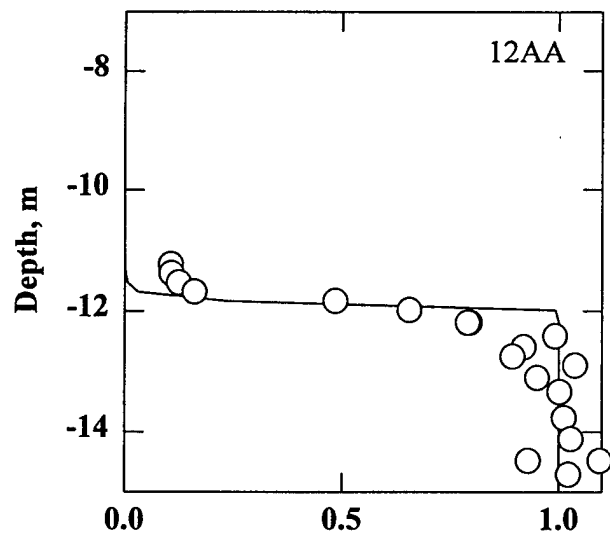
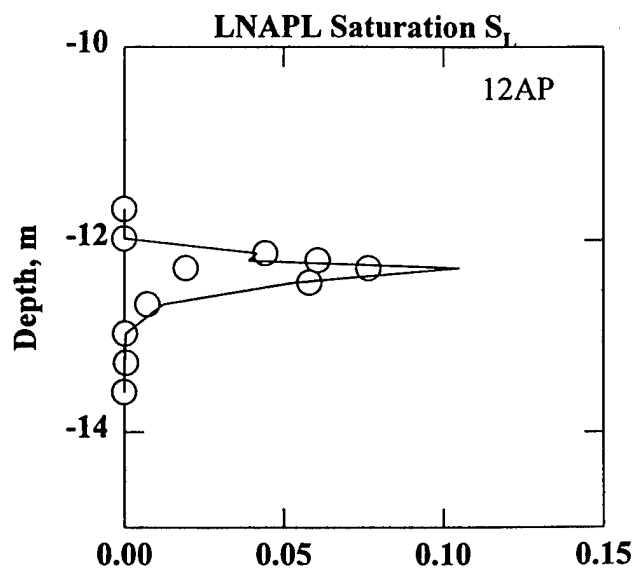
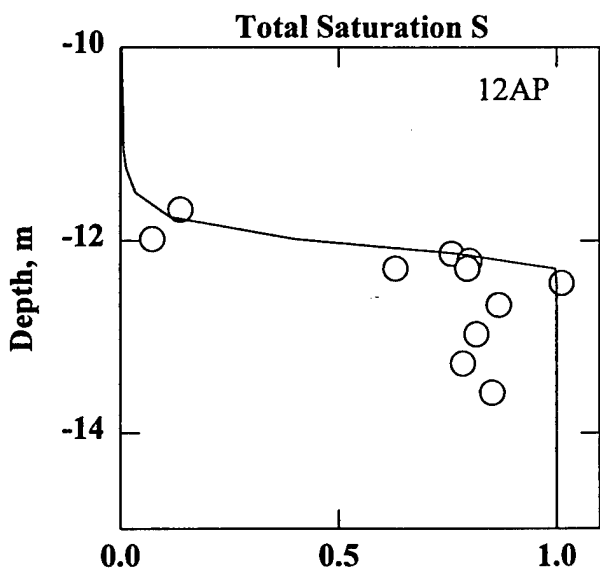
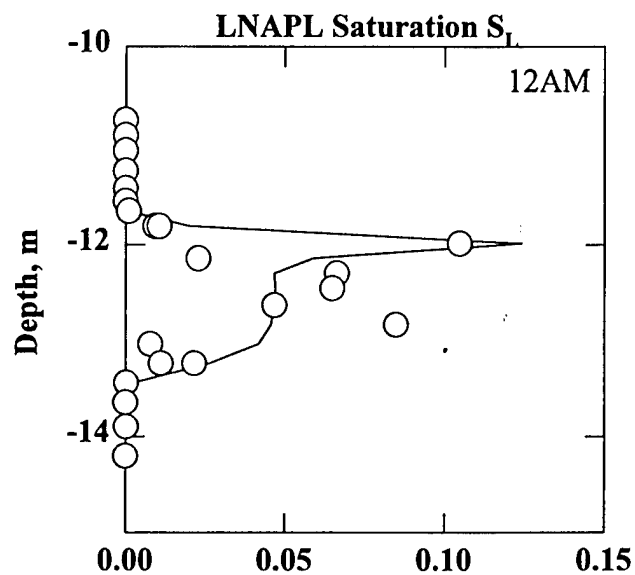
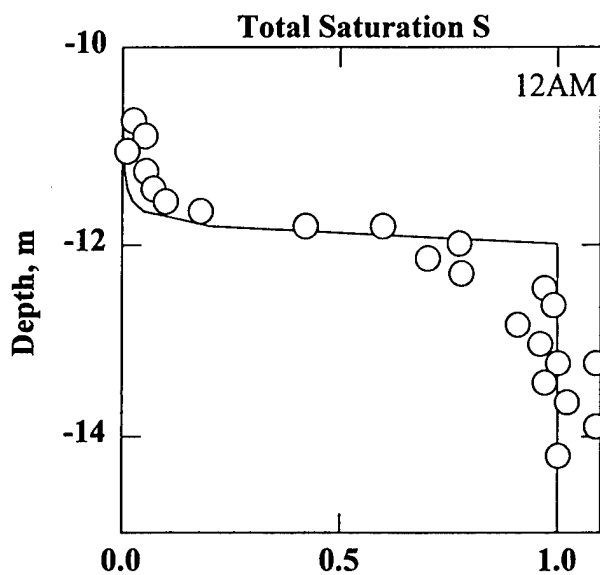
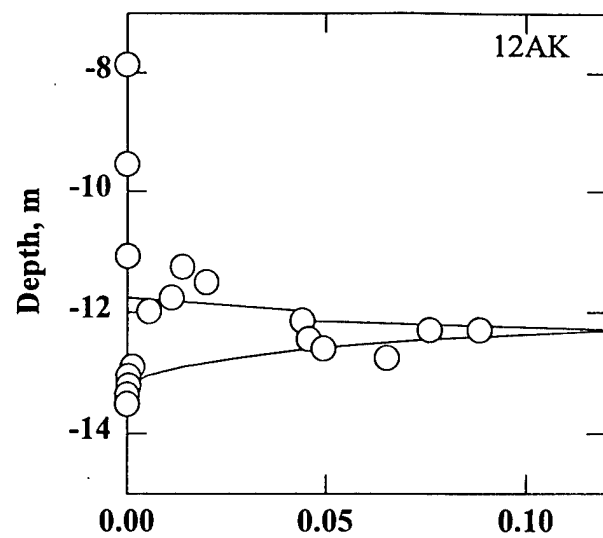
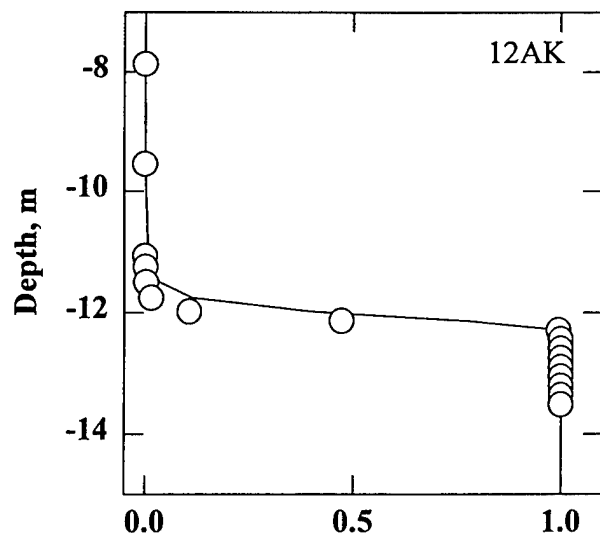


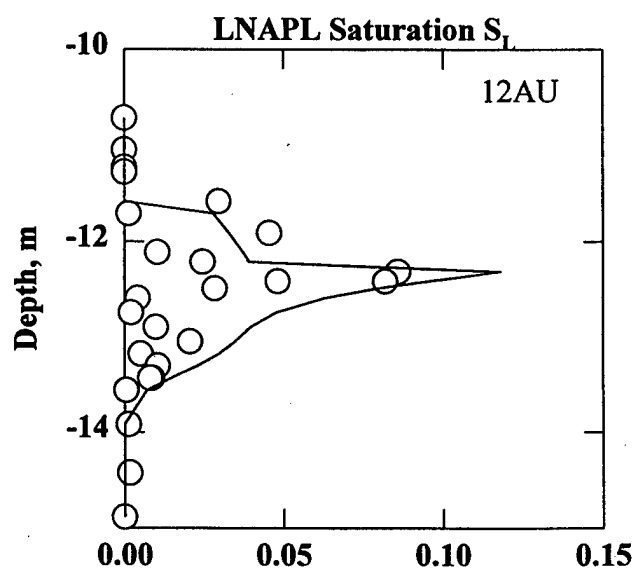
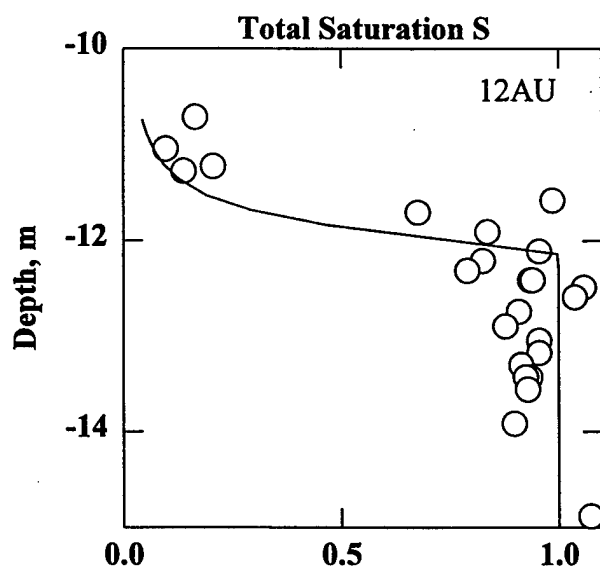
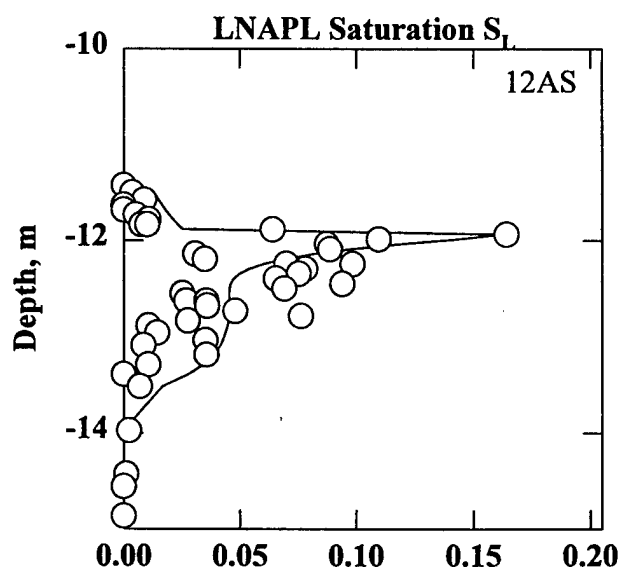
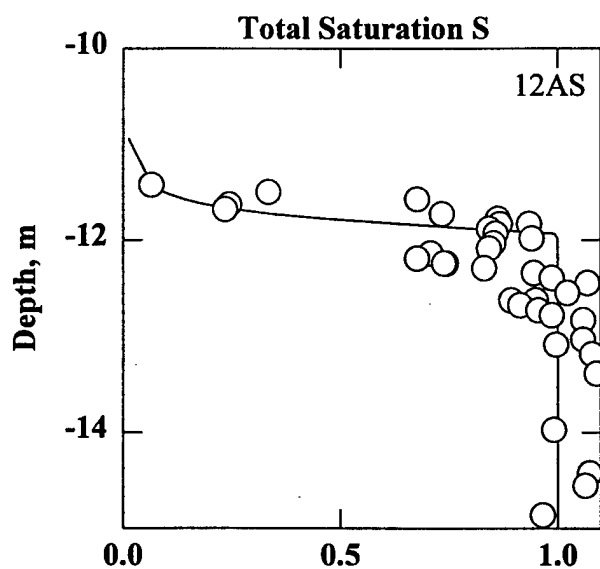
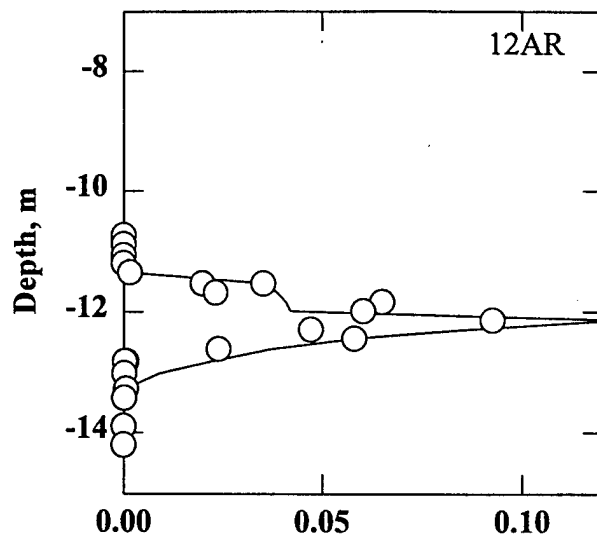
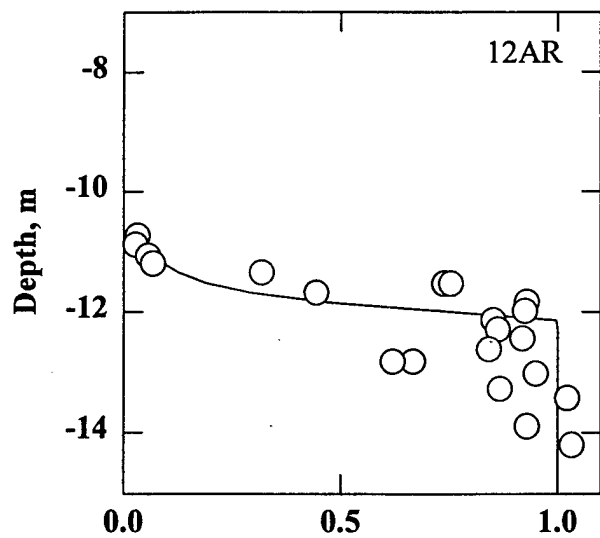
Figure 5.7 Observed (Symbols) and Calibrated Total and LNAPL Saturations



Total Saturation S

LNAPL Saturation S_L

Figure 5.7 (Continued) Observed (Symbols) and Calibrated Total and LNAPL Saturations



Total Saturation S

LNAPL Saturation S_L

Figure 5.7 (Continued) Observed (Symbols) and Calibrated Total and LNAPL Saturations

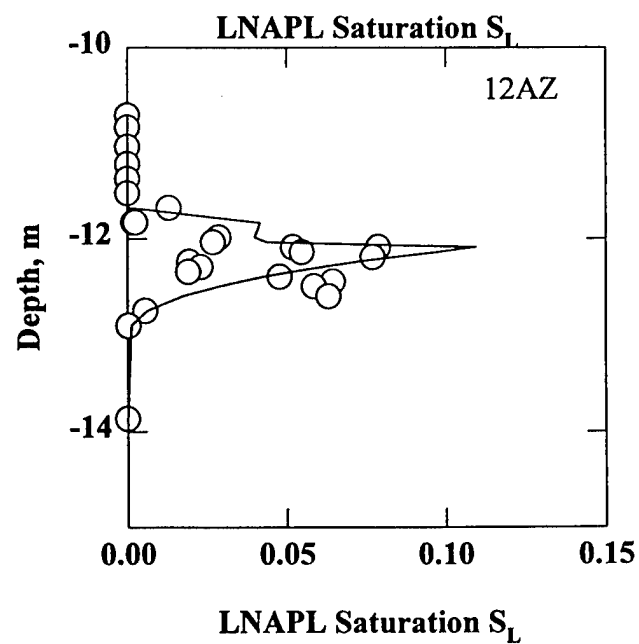
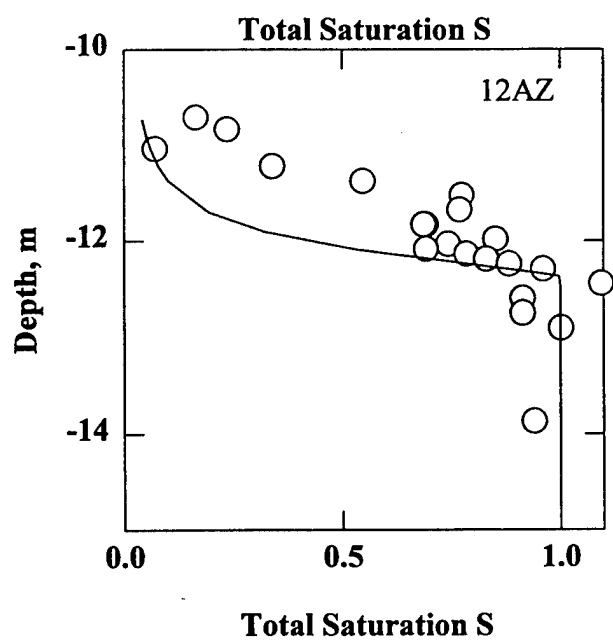
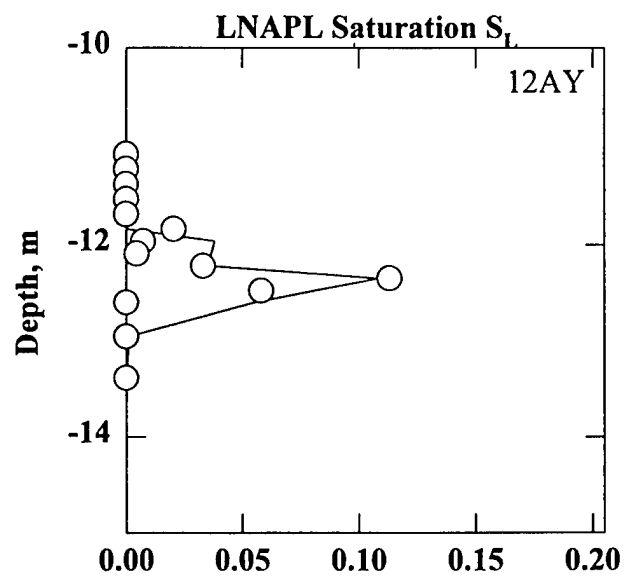
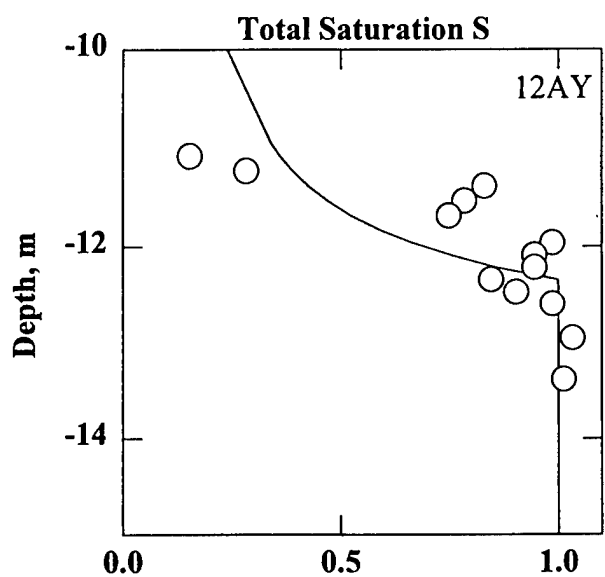
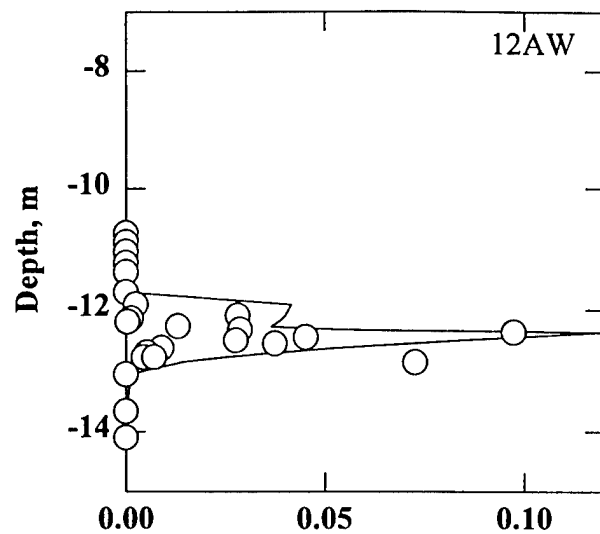
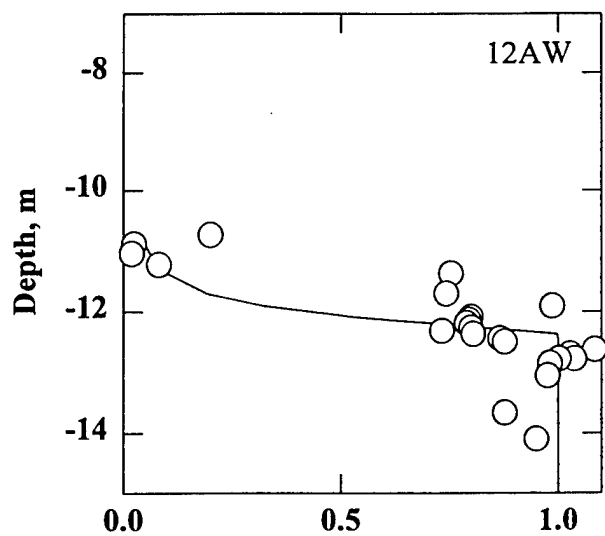
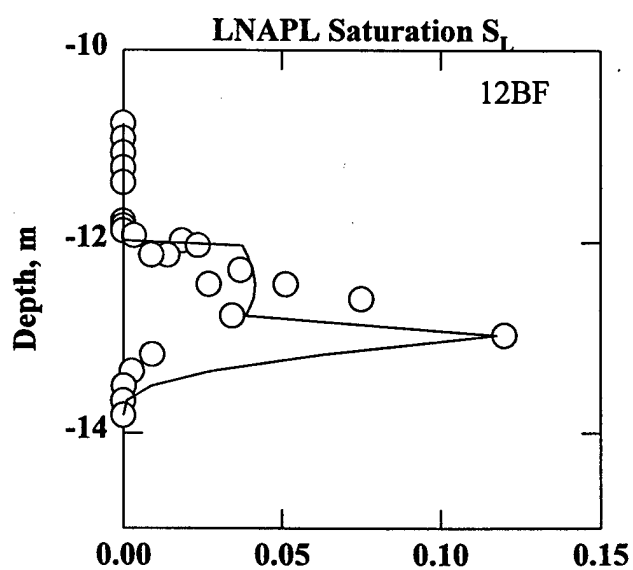
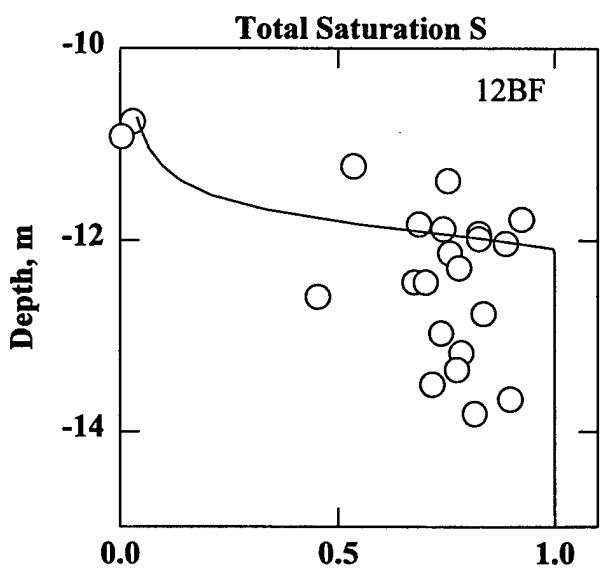
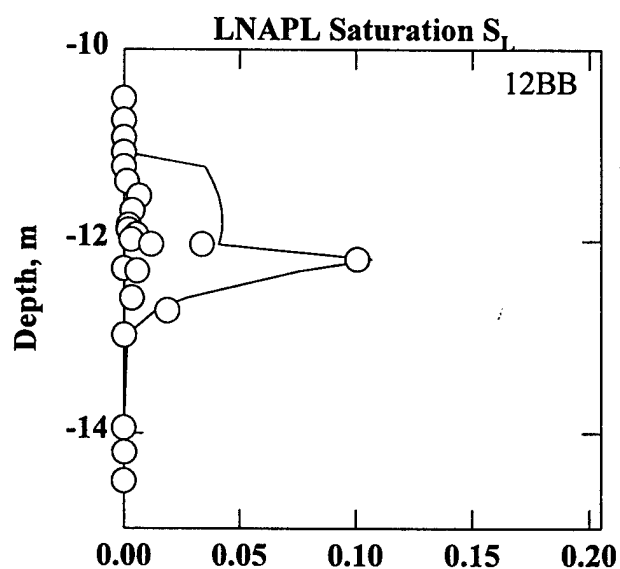
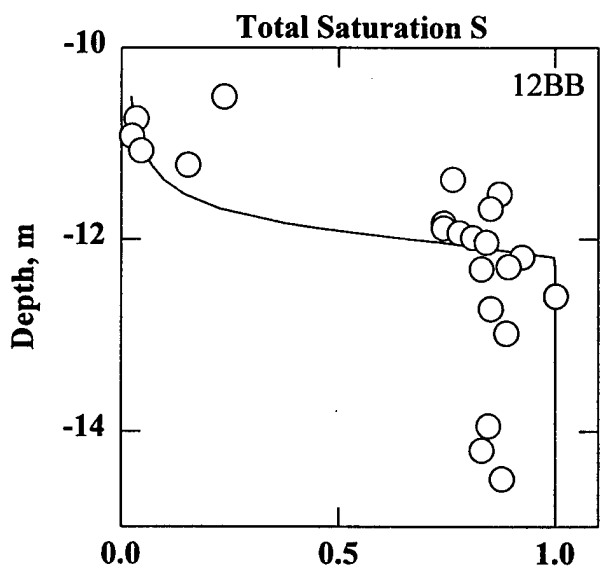
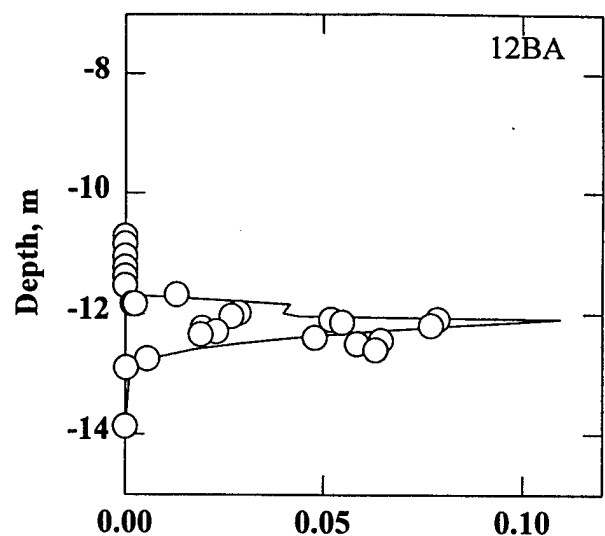
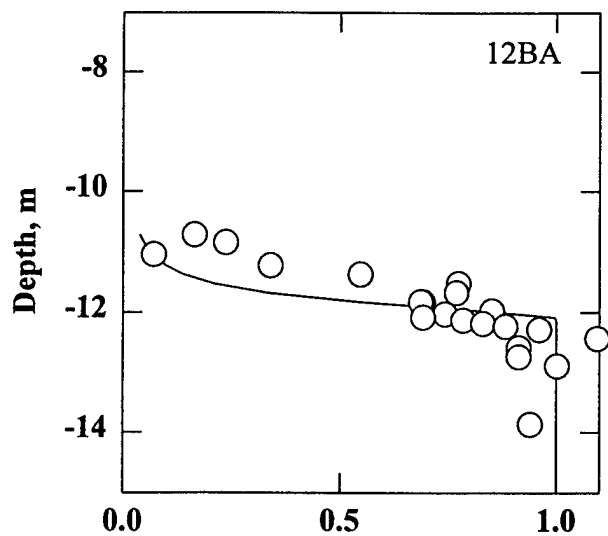


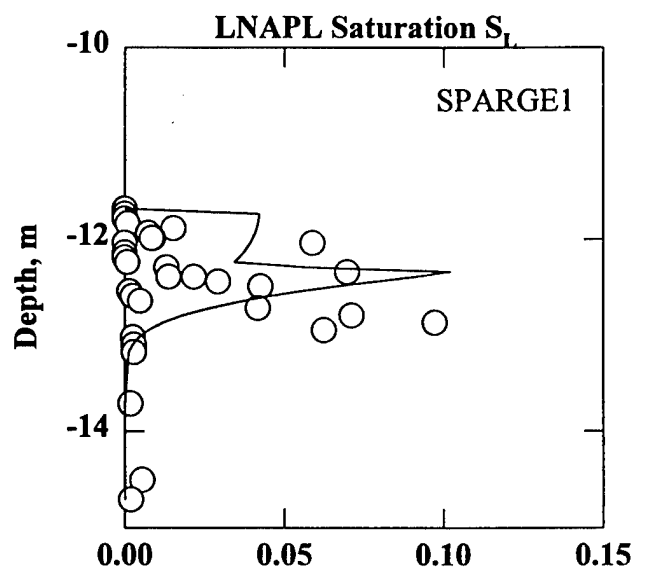
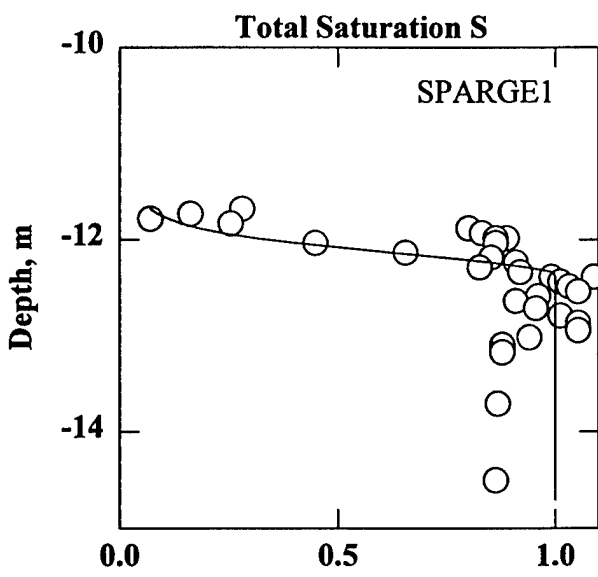
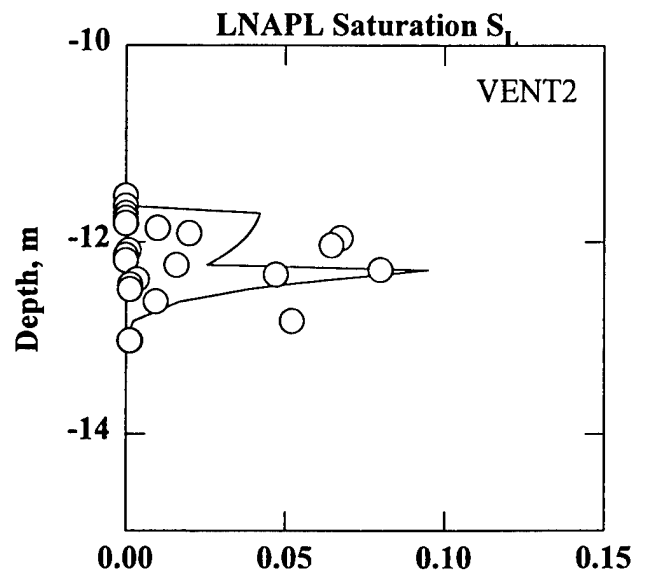
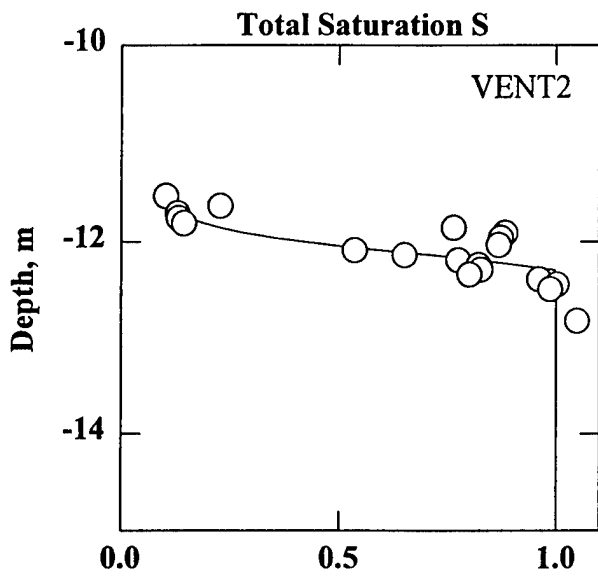
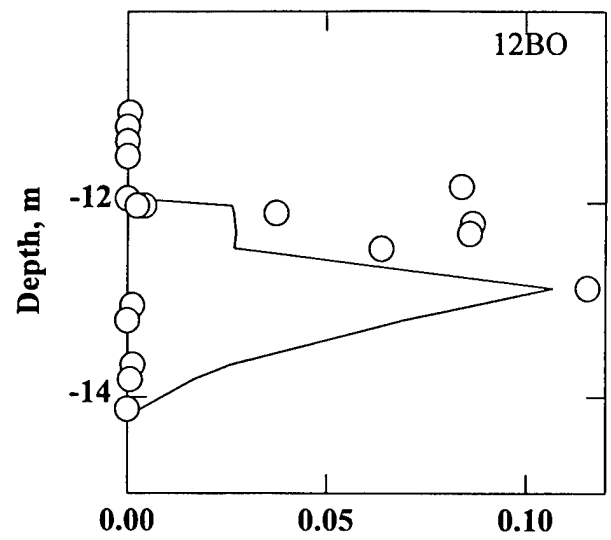
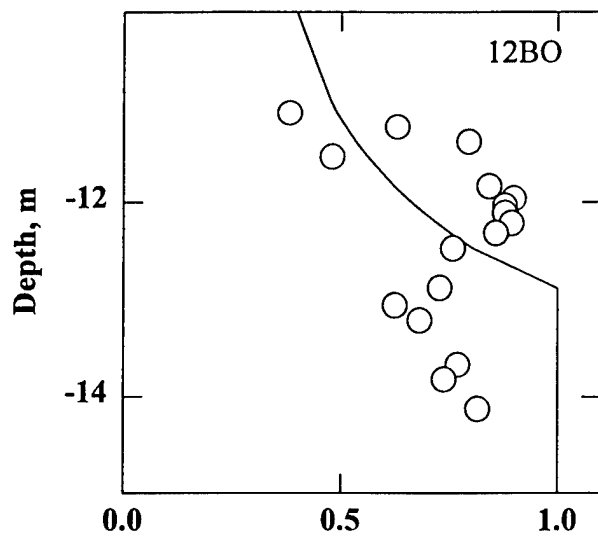
Figure 5.7 (Continued) Observed (Symbols) and Calibrated Total and LNAPL Saturations



Total Saturation S

LNAPL Saturation S_L

Figure 5.7 (Continued) Observed (Symbols) and Calibrated Total and LNAPL Saturations



Total Saturation S

LNAPL Saturation S_L

Figure 5.7 (Continued) Observed (Symbols) and Calibrated Total and LNAPL Saturations

scaling factor ranges from 3.34 to 19.8 m⁻¹ in magnitude. The average values of the 18 calibrations is

$$\alpha_P = 3.87 \quad (5.23a)$$

$$\beta_L = 8.21 \quad (5.23b)$$

$$r_M = 0.046 \text{ mm} \quad (5.23c)$$

The average pore radius implied by Equation 5.23b follows from Equations 4.6a and 5.16b, and is used to model the distribution of both water and separate phase JP4 jet fuel. The average pore size uniformity exponent is remarkably close to its grain size counterpart (α_D) of 3.68 (Equation 5.7b). The correspondence of these independently calibrated exponents is physically plausible, since the grain size distribution determines the distribution of the pore spaces between the solids in a porous medium.

We deduce a relation between the mean pore radius and the mean grain size by approximating the numbers N_P and N_D of pores and grains in a representative soil volume

$$\frac{N_P \left(\frac{4\pi r_M^3}{3} \right)}{N_D \left(\frac{\pi d_M^3}{6} \right)} = \frac{n}{1-n} \quad (5.24)$$

The numerator of Equation 5.24 is proportional to the pore volume while the denominator is proportional to the solid grain volume. We equate the surface area of the pores to the surface area of the grains in the representative volume in deriving a second equation for the N_P to N_D ratio with the result

$$N_D \pi d_M^2 = N_P 4\pi r_M^2 \quad (5.25a)$$

$$r_M = d_M \frac{n}{2(1-n)} \quad (d_M = 0.441 \text{ mm}) \quad (5.25b)$$

The d_M listed in Equation 5.23b is the average of the Table 5.3 values, and implies a pore size radius of 0.12 mm. This is somewhat larger than Equation 5.23c, but still within an order of magnitude of the moisture based calibrated value.

5.2.3 Separate Phase Trichloroethylene Profiles

We observed trichloroethylene in the LNAPL extract chromatograms for boreholes 12AS, 12AV, 12BB, 12BF, 12BI, and 12BO. Tables 5.7-5.12 list the separate phase TCE

TABLE 5.7 LNAPL AND TCE CONTENT IN BOREHOLE 12AS

| Depth, m | T_{TCE}, mg/kg | T, mg/kg | T_{TCE}/T | Depth, m | T_{TCE}, mg/kg | T, mg/kg | T_{TCE}/T |
|---------------------|-----------------------------------|-----------------|--------------------------|---------------------|-----------------------------------|-----------------|--------------------------|
| 11.49 | 0.18 | 602 | 0.00030 | 12.49 | 11.91 | 11086 | 0.00108 |
| 11.49 | 0.21 | 602 | 0.00036 | 12.54 | 7.23 | 4032 | 0.00179 |
| 11.73 | 0.56 | 824 | 0.00068 | 12.61 | 0.00 | 5689 | 0 |
| 11.78 | 1.00 | 1703 | 0.00059 | 12.61 | 7.31 | 4311 | 0.00170 |
| 11.78 | 1.08 | 1703 | 0.00063 | 12.67 | 3.74 | 5739 | 0.00065 |
| 11.83 | 1.08 | 1220 | 0.00088 | 12.72 | 20.10 | 7697 | 0.00261 |
| 11.83 | 1.11 | 1618 | 0.00068 | 12.77 | 10.01 | 12228 | 0.00082 |
| 11.88 | 25.23 | 10284 | 0.00245 | 12.82 | 1.37 | 4414 | 0.00031 |
| 11.93 | 58.60 | 26335 | 0.00223 | 12.88 | 0.30 | 1694 | 0.00028 |
| 11.98 | 37.72 | 17593 | 0.00214 | 12.94 | 0.34 | 2285 | 0.00015 |
| 12.04 | 29.70 | 14021 | 0.00212 | 13.02 | 5.83 | 5644 | 0.00103 |
| 12.04 | 29.26 | 14021 | 0.00209 | 13.08 | 4.66 | 1360 | 0.00343 |
| 12.09 | 35.73 | 14241 | 0.00251 | 13.18 | 10.04 | 5701 | 0.00176 |
| 12.14 | 11.49 | 4917 | 0.00234 | 13.28 | 0.93 | 1678 | 0.00056 |
| 12.19 | 10.74 | 5586 | 0.00192 | 13.51 | 0.49 | 1129 | 0.00044 |
| 12.19 | 9.64 | 5586 | 0.00173 | 13.66 | 0.46 | 688 | 0.00067 |
| 12.24 | 42.77 | 15796 | 0.00271 | 13.82 | 0.29 | 572 | 0.00051 |
| 12.24 | 31.37 | 11226 | 0.00279 | 13.97 | 0.04 | 383 | 0.00010 |
| 12.29 | 0.00 | 12536 | 0 | 14.12 | 0.11 | 458 | 0.00023 |
| 12.34 | 26.24 | 12087 | 0.00217 | 14.27 | 0.17 | 418 | 0.00040 |
| 12.39 | 21.48 | 10514 | 0.00204 | 14.43 | 0.05 | 153 | 0.00035 |
| 12.44 | 0.00 | 15078 | 0 | | | | |

concentrations T_{TCE} along with the total LNAPL content in the profiles. We observed the following maximum (T_{TCEMAX}) levels in the six boreholes:

- borehole 12AS-T_{TCEMAX}=58.6 mg/kg
- borehole 12AV-T_{TCEMAX}=47.3 mg/kg
- borehole 12BB-T_{TCEMAX}=24.5 mg/kg
- borehole 12BF-T_{TCEMAX}=47.0 mg/kg
- borehole 12BI-T_{TCEMAX}=21.2 mg/kg
- borehole 12BO-T_{TCEMAX}=113 mg/kg

Figure 5.8 displays the separate phase TCE profiles, which exhibit a vertical structure similar to their total LNAPL counterparts in Figure 5.7. The TCE maxima occur near the water table and coincide with the T_{MAX} depths.

The ratio of separate phase trichloroethylene to total LNAPL is also cited in Tables 5.7-5.12, and is plotted a function of depth in Figure 5.9. Trichloroethylene is less than 2% of the total LNAPL (by mass), with an average value for 95 samples of

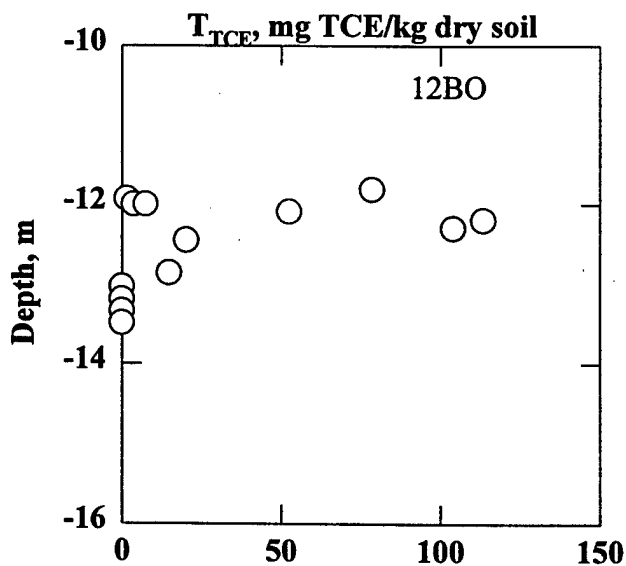
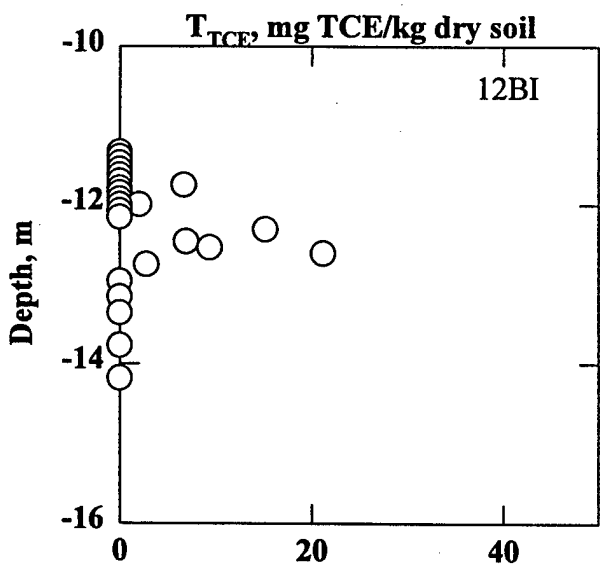
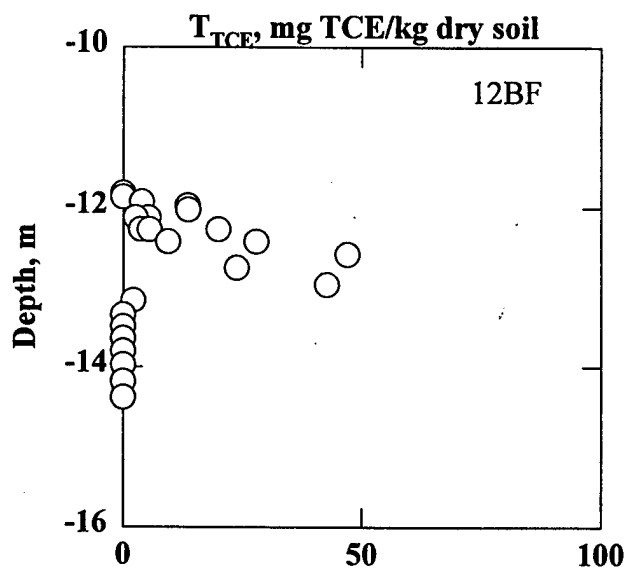
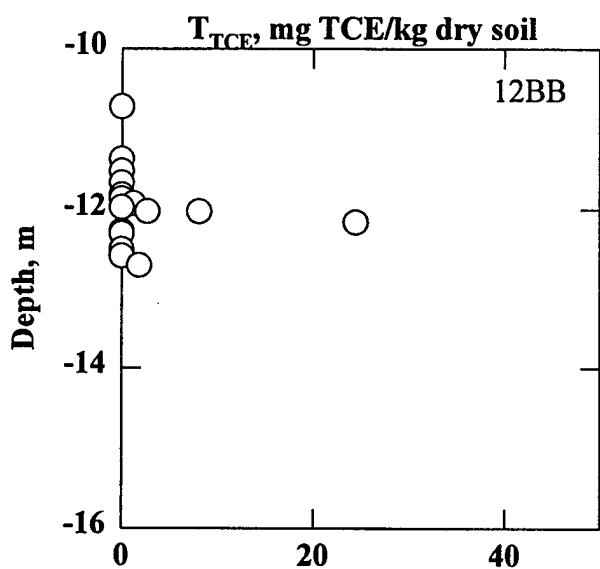
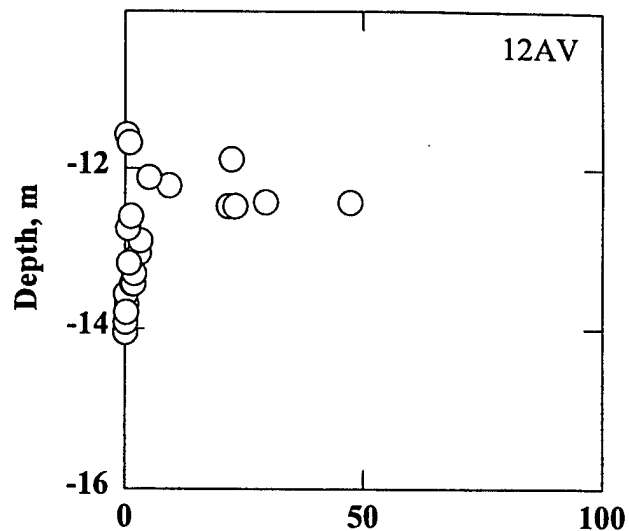
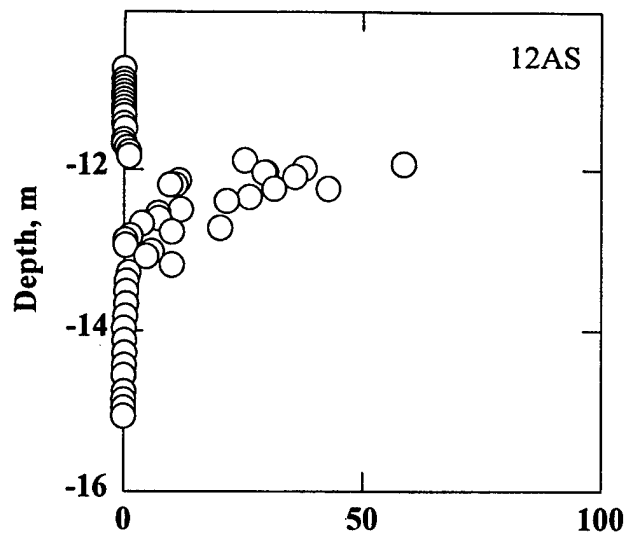


Figure 5.8 Observed Separate Phase Trichloroethylene Content in Solid Core Boreholes

TABLE 5.8 LNAPL AND TCE CONTENT IN BOREHOLE 12AV

| Depth, m | T _{TCE} , mg/kg | T, mg/kg | T _{TCE} /T | Depth, m | T _{TCE} , mg/kg | T, mg/kg | T _{TCE} /T |
|-------------|-----------------------------|----------|---------------------|-------------|-----------------------------|----------|---------------------|
| 11.68 | 1 | 231 | 0.00433 | 13.05 | 2.99 | 3312 | 0.00090 |
| 11.88 | 22.4 | 7324 | 0.00306 | 13.18 | 0.9 | 816 | 0.00110 |
| 12.11 | 5.09 | 1669 | 0.00305 | 13.31 | 1.98 | 1691 | 0.00117 |
| 12.21 | 9.34 | 3947 | 0.00237 | 13.44 | 1.54 | 1394 | 0.00111 |
| 12.42 | 29.64 | 7732 | 0.00383 | 13.44 | 1.79 | 1394 | 0.00128 |
| 12.42 | 47.28 | 13156 | 0.00359 | 13.44 | 1.84 | 1293 | 0.00142 |
| 12.47 | 21.8 | 4558 | 0.00478 | 13.56 | 0.24 | 89 | 0.00267 |
| 12.47 | 23.19 | 4558 | 0.00509 | 13.69 | 0.37 | 161 | 0.00230 |
| 12.60 | 1.34 | 679 | 0.00197 | 13.79 | 0.36 | 412 | 0.00087 |
| 12.75 | 0.7 | 340 | 0.00206 | 13.92 | 0.17 | 210 | 0.00081 |
| 12.90 | 3.3 | 1594 | 0.00207 | | | | |

TABLE 5.9 LNAPL AND TCE CONTENT IN BOREHOLE 12BB

| Depth, m | T _{TCE} , mg/kg | T, mg/kg | T _{TCE} /T | Depth, m | T _{TCE} , mg/kg | T, mg/kg | T _{TCE} /T |
|-------------|-----------------------------|----------|---------------------|-------------|-----------------------------|----------|---------------------|
| 11.36 | 0.00 | 185 | 0.00000 | 12.16 | 24.46 | 16164 | 0.00151 |
| 11.51 | 0.00 | 1039 | 0.00000 | 12.30 | 0.00 | 912 | 0.00000 |
| 11.66 | 0.00 | 582 | 0.00000 | 12.30 | 0.00 | 669 | 0.00000 |
| 11.81 | 0.00 | 343 | 0.00000 | 12.50 | 0.00 | 809 | 0.00000 |
| 11.86 | 0.00 | 316 | 0.00000 | 12.58 | 0.00 | 553 | 0.00000 |
| 11.92 | 1.21 | 850 | 0.00142 | 12.70 | 1.83 | 3000 | 0.00061 |
| 11.97 | 0.00 | 498 | 0.00000 | 12.96 | 0.00 | 17 | 0.00000 |
| 12.02 | 2.68 | 5388 | 0.00050 | 12.96 | 0.00 | 16 | 0.00000 |
| 12.02 | 8.07 | 1877 | 0.00430 | 13.26 | 0.00 | 21 | 0.00000 |

$$\frac{T_{TCE}}{T} = 0.00253 \quad (5.26a)$$

$$\chi_{TCE} = \frac{T_{TCE}}{T} \frac{m_G}{m_Y} \quad (5.26b)$$

$$\chi_{TCE} = 0.00222 \quad (\text{separate phase}) \quad (5.26c)$$

The molar masses for TCE and total hydrocarbons cited in Equation 4.15 convert this mass fraction to the separate phase mole fraction χ_{TCE} in Equation 5.26c. The separate phase mole fraction is important because it specifies the saturated TCE vapor concentration Y_{SAT} by virtue of

TABLE 5.10 LNAPL AND TCE CONTENT IN BOREHOLE 12BF

| Depth, m | T _{TCE} , mg/kg | T, mg/kg | T _{TCE} /T | Depth, m | T _{TCE} , mg/kg | T, mg/kg | T _{TCE} /T |
|-------------|-----------------------------|----------|---------------------|-------------|-----------------------------|----------|---------------------|
| 11.92 | 3.90 | 535 | 0.00729 | 12.42 | 9.43 | 4328 | 0.00218 |
| 11.97 | 13.50 | 2970 | 0.00455 | 12.42 | 27.90 | 8242 | 0.00339 |
| 12.02 | 13.57 | 3778 | 0.00359 | 12.58 | 47.01 | 12061 | 0.00390 |
| 12.12 | 5.30 | 2241 | 0.00236 | 12.75 | 23.80 | 5516 | 0.00432 |
| 12.12 | 2.61 | 1429 | 0.00182 | 12.96 | 42.64 | 19253 | 0.00221 |
| 12.27 | 19.89 | 1882 | 0.01057 | 13.16 | 2.11 | 1471 | 0.00144 |
| 12.27 | 3.71 | 5944 | 0.00062 | 13.34 | 0.00 | 443 | 0.00000 |
| 12.27 | 5.52 | 2054 | 0.00269 | | | | |

TABLE 5.11 LNAPL AND TCE CONTENT IN BOREHOLE 12BI

| Depth, m | T _{TCE} , mg/kg | T, mg/kg | T _{TCE} /T | Depth, m | T _{TCE} , mg/kg | T, mg/kg | T _{TCE} /T |
|-------------|-----------------------------|----------|---------------------|-------------|-----------------------------|----------|---------------------|
| 11.62 | 0.00 | 666 | 0.00000 | 12.46 | 6.91 | 1867 | 0.00370 |
| 11.70 | 0.00 | 994 | 0.00000 | 12.54 | 9.34 | 2592 | 0.00360 |
| 11.75 | 6.68 | 1853 | 0.00361 | 12.61 | 21.19 | 5748 | 0.00369 |
| 11.79 | 0.00 | 1727 | 0.00000 | 12.75 | 2.78 | 3416 | 0.00081 |
| 11.85 | 0.00 | 1035 | 0.00000 | 12.96 | 0.00 | 288 | 0.00000 |
| 11.93 | 0.00 | 298 | 0.00000 | 12.96 | 0.00 | 199 | 0.00000 |
| 12.00 | 2.06 | 745 | 0.00277 | 13.16 | 0.00 | 435 | 0.00000 |
| 12.00 | 0.00 | 805 | 0.00000 | 13.36 | 0.00 | 192 | 0.00000 |
| 12.08 | 0.00 | 9119 | 0.00000 | 13.77 | 0.00 | 84 | 0.00000 |
| 12.16 | 0.00 | 9123 | 0.00000 | 14.18 | 0.00 | 719 | 0.00000 |
| 12.31 | 15.16 | 5350 | 0.00283 | | | | |

TABLE 5.12 LNAPL AND TCE CONTENT IN BOREHOLE 12BO

| Depth, m | T _{TCE} , mg/kg | T, mg/kg | T _{TCE} /T | Depth, m | T _{TCE} , mg/kg | T, mg/kg | T _{TCE} /T |
|-------------|-----------------------------|----------|---------------------|-------------|-----------------------------|----------|---------------------|
| 11.81 | 78.62 | 13457 | 0.00584 | 12.30 | 104.00 | 13800 | 0.00754 |
| 12.00 | 3.66 | 681 | 0.00537 | 12.45 | 20.17 | 10247 | 0.00197 |
| 12.00 | 7.40 | 385 | 0.01922 | 12.86 | 14.80 | 18536 | 0.00080 |
| 12.09 | 52.54 | 6001 | 0.00876 | 13.03 | 0.00 | 204 | 0.00000 |
| 12.20 | 113.36 | 13907 | 0.00815 | | | | |

Raoult's law [Eastman (1975)]

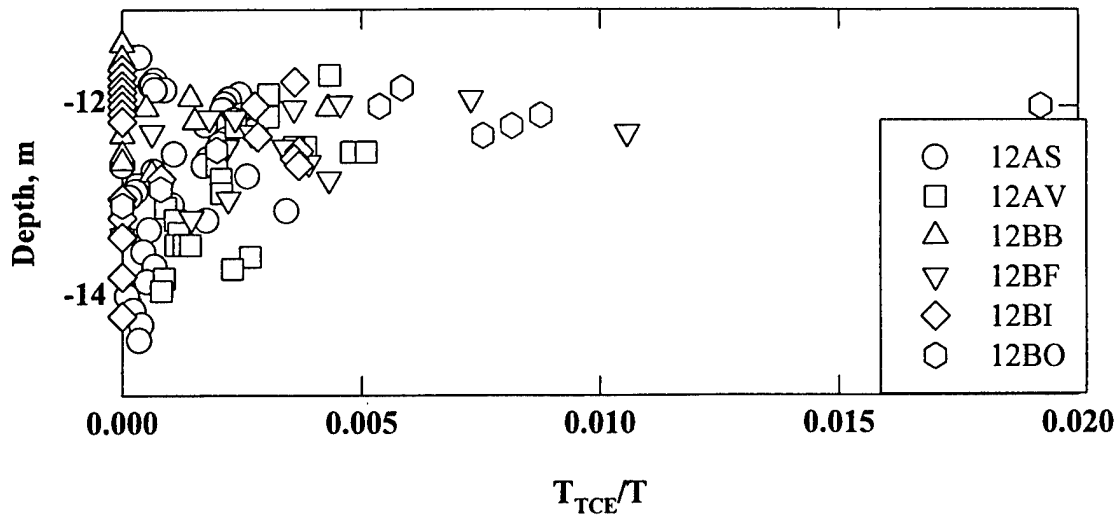


Figure 5.9 Ratio of Separate Phase Trichloroethylene to Total Petroleum Hydrocarbons in Solid Core Samples

$$Y_{\text{SAT}} = Y_{\text{PURE}} \chi_{\text{TCE}} \quad (5.27a)$$

$$Y_{\text{PURE}} = 0.422 \frac{\text{kg}}{\text{m}^3} \quad (293^\circ\text{K}) \quad (5.27b)$$

The ideal gas law [Eastman (1975)] is used to compute the saturated vapor concentration above pure trichloroethylene Y_{PURE} from the saturated pressure value p_{YPURE} cited by Mackay and Shiu (1981)

$$Y_{\text{PURE}} = \frac{p_{\text{YPURE}} m_{\text{TCE}}}{R_U T} \quad (5.28a)$$

$$R_U = 8.31 \frac{\text{mole} \cdot \text{m}^3}{^\circ\text{K} \cdot \text{Pa}} \quad (5.28b)$$

$$p_{\text{YPURE}} = 7.86 \times 10^3 \text{ Pa} \quad (293^\circ\text{K}) \quad (5.28c)$$

Equations 5.27 and 5.28 yield estimates of the (293°K) saturated TCE vapor pressure and concentration in the separate phase contaminated soil at Plattsburgh

$$Y_{\text{SAT}} \approx 9.39 \times 10^{-4} \frac{\text{kg}}{\text{m}^3} \quad (5.29a)$$

$$p_{\text{YSAT}} \approx 17.4 \text{ Pa}$$

$$(p_{\text{YSAT}} \approx 174 \text{ ppm}) \quad (5.29b)$$

5.3 Soil Vapor Concentrations

5.3.1 Ambient Soil Vapor Calibrations

Tables 5.13-5.29 list the total hydrocarbon, oxygen, carbon dioxide, and trichloroethylene vapor pressure data observed in the soil gas tubing clusters by UMASS researchers. The helium tracer test data are summarized in Table 5.30, while the soil vapor probe data are presented in Tables 5.31-5.40. We distinguish ambient, venting, and sparging data bases, depending on the presence of air injection at or below the capillary fringe:

Ambient data base

- Clusters 12AN, 12AT, and 12AX: All dates
- Clusters 12AA-12AM, 12AO-12AR, 12AU-12AW, 12AZ, and 12BA: 26Oct95 through 16Jan96
- Vapor probes VP1, VP2, and VP3

Soil venting data base

- Clusters 12AA-12AM, 12AO-12AR, 12AU-12AW, 12AZ, and 12BA: 17Jan96 through 15Jul96

Air sparging data base

- Clusters 12AA-12AM, 12AO-12AR, 12AU-12AW, 12AZ, and 12BA: 20Aug96 through 19Dec96
- Vapor probes 12BC, 12BE, 12BH, 12BJ, 12BK, 12BM, and 12BN

We calibrate the coupled, first order, steady state, ambient oxygen and carbon dioxide models (Equation 4.27) with the data from clusters 12AN, 12AT, and 12AX with the results summarized in Figure 5.10. We adopt zero CO_2 and an atmospheric oxygen value X_0 of 0.288 kg/m^3 (20.9% by volume at 282°K) as surface boundary conditions. A Fibonacci search through the combined data sets minimizes the error mean δ_{XCM} and standard deviation σ_{XC} defined by

$$\delta_{\text{X}} = \frac{X(\text{measured}) - X(\text{predicted})}{X(\text{predicted})} \quad (5.30a)$$

$$\delta_{\text{C}} = \frac{C(\text{measured}) - C(\text{predicted})}{C(\text{predicted})} \quad (5.30b)$$

$$\delta_{\text{XCM}} = \frac{1}{2N} \sum_N (\delta_{\text{X}} + \delta_{\text{C}}) \quad (5.30c)$$

$$\sigma_{\text{XC}} = \sqrt{\frac{1}{2N} \sum_N (\delta_{\text{X}}^2 + \delta_{\text{C}}^2) - \delta_{\text{XCM}}^2} \quad (5.30d)$$

**TABLE 5.13 SOIL GAS CONSTITUENTS IN TUBING CLUSTERS
26 OCTOBER 1995**

| Sample ID | Depth, m | p_G, ppm^a | p_X, %^a | p_C, %^a |
|------------------|-----------------|---------------------------------------|-------------------------------------|-------------------------------------|
| 12AA | 7.3 | 230 | 9.8 | 7.9 |
| 12AB | 0.9 | 60 | 18.4 | 2.2 |
| | 4.6 | 110 | 15.4 | 4.6 |
| 12AC | 1.8 | 60 | 18.6 | 2.1 |
| | 5.5 | 100 | 15.5 | 3.3 |
| 12AD | 3.7 | 60 | 17.3 | 2.1 |
| | 7.3 | 180 | 9.8 | 5.9 |
| 12AE | 1.8 | 40 | 18.5 | 2.2 |
| | 5.3 | 80 | 15.7 | 4.3 |
| 12AF | 1.8 | 30 | 19.0 | 1.5 |
| | 5.0 | 60 | 15.7 | 3.7 |
| 12AG | 0.9 | 40 | 19.1 | 1.5 |
| | 4.6 | 60 | 17.0 | 2.9 |
| 12AH | 3.7 | 90 | 16.8 | 3.1 |
| | 9.1 | 200 | 6.0 | 9.6 |
| 12AI | 2.7 | 40 | 18.0 | 2.5 |
| | 8.7 | 140 | 5.3 | 9.5 |
| 12AJ | 1.8 | 20 | 18.8 | 1.1 |
| | 5.5 | 60 | 15.0 | 3.5 |
| 12AK | 3.7 | 60 | 15.9 | 4.3 |
| | 9.1 | 220 | 5.4 | 7.8 |
| 12AL | 0.9 | 40 | 18.6 | 1.8 |
| | 4.6 | 60 | 16.4 | 3.8 |
| 12AM | 11.1 | NS ^b | NS | NS |
| 12AN | 1.8 | 60 | 16.2 | 4.6 |
| | 5.2 | 90 | 12.6 | 7.9 |
| | 8.2 | 120 | 14.0 | 4.5 |
| 12AO | 3.7 | 40 | 18.0 | 2.9 |
| | 9.1 | 460 | 2.5 | 11.2 |
| 12AP | 2.7 | 40 | 18.5 | 2.4 |
| | 7.3 | 140 | 10.8 | 7.4 |
| 12AQ | 2.7 | 40 | 18.4 | 2.7 |
| | 7.3 | 80 | 12.6 | 6.7 |
| 12AR | 0.9 | 0 | 19.6 | 1.7 |
| | 4.6 | 60 | 16.8 | 4.2 |
| 12AT | 9.4 | NS | NS | NS |
| CONTROL | 3.7 | 0 | 20.8 | 0.2 |
| CONTROL | 7.3 | 0 | 20.8 | 0.2 |

^aBy volume.

^bNot sampled.

TABLE 5.14 SOIL GAS CONSTITUENTS IN TUBING CLUSTERS
16 NOVEMBER 1995

| Sample ID | Depth, m | P _G , ppm ^a | P _X , % ^a | P _C , % ^a |
|-----------|----------|-----------------------------------|---------------------------------|---------------------------------|
| 12AA | 7.3 | 100 | 11 | 7.2 |
| 12AB | 0.9 | 40 | 18.7 | 2.1 |
| | 4.6 | 60 | 15 | 5.6 |
| 12AC | 1.8 | 110 | 19.3 | 0.9 |
| | 5.5 | 140 | 15.5 | 1.9 |
| 12AD | 3.7 | 40 | 17.8 | 2.0 |
| | 7.3 | 80 | 11.7 | 4.3 |
| 12AE | 1.8 | 45 | 19.1 | 1.4 |
| | 5.3 | 80 | 16.4 | 2.8 |
| 12AF | 1.8 | 40 | 19.4 | 0.9 |
| | 5 | 60 | 16.7 | 2.2 |
| 12AG | 0.9 | 40 | 19.5 | 0.7 |
| | 4.6 | 80 | 18.2 | 1.8 |
| 12AH | 3.7 | 10 | 17 | 3.5 |
| | 9.1 | 160 | 9.2 | 9.5 |
| 12AI | 2.7 | 40 | 18.7 | 1.6 |
| | 8.7 | 100 | 7.3 | 7.3 |
| 12AJ | 1.8 | 60 | 19.3 | 0.8 |
| | 5.5 | 60 | 14.4 | 4.2 |
| 12AK | 3.7 | 80 | 16.1 | 3.0 |
| | 9.1 | 100 | 8 | 17.3 |
| 12AL | 0.9 | 60 | 19 | 1.0 |
| | 4.6 | 80 | 16.2 | 2.7 |
| 12AM | 11.1 | 80 | 6.9 | 7.0 |
| 12AN | 1.8 | 80 | 17 | 3.5 |
| | 5.2 | 90 | 12.9 | 6.8 |
| | 8.2 | 100 | 10 | 6.0 |
| 12AO | 3.7 | 60 | 17.7 | 2.2 |
| | 9.1 | 100 | 15.8 | 8.3 |
| 12AP | 2.7 | 40 | 19 | 1.3 |
| | 7.3 | 60 | 11.3 | 5.7 |
| 12AQ | 2.7 | 30 | 18.6 | 1.6 |
| | 7.3 | 80 | 12.6 | 3.9 |
| 12AR | 0.9 | 20 | 19.8 | 0.7 |
| | 4.6 | 60 | 16.3 | 3.0 |
| 12AT | 9.4 | NS ^b | NS | NS |
| CONTROL | 3.7 | 0 | 20.7 | 0.0 |
| CONTROL | 7.3 | 0 | 20.7 | 0.0 |

^aBy volume.

^bNot sampled.

TABLE 5.15 SOIL GAS CONSTITUENTS IN TUBING CLUSTERS
16 JANUARY 1996

| Sample ID | Depth, m | p _G , ppm ^a | p _X , % ^a | p _C , % ^a | p _Y , ppm ^a |
|-----------|----------|-----------------------------------|---------------------------------|---------------------------------|-----------------------------------|
| 12AA | 7.3 | 70 | 11 | 7 | 18 |
| 12AB | 0.9 | 30 | 18 | 2 | NS |
| | 4.6 | 60 | 16 | 4 | NS |
| 12AC | 1.8 | 20 | 19 | 1 | NS |
| | 5.5 | 50 | 16 | 3 | 2 |
| 12AD | 3.7 | 40 | 19 | 2 | NS |
| | 7.3 | 100 | 11 | 7 | 19 |
| 12AE | 1.8 | 20 | 19 | 1 | NS |
| | 5.3 | 60 | 17 | 3 | 2 |
| 12AF | 1.8 | 20 | 20 | 1 | NS |
| | 5 | 40 | 18 | 2 | NS |
| 12AG | 0.9 | 20 | 20 | 1 | NS |
| | 4.6 | 40 | 19 | 2 | NS |
| 12AH | 3.7 | 40 | 18 | 2 | NS |
| | 9.1 | 100 | 8 | 9 | 20 |
| 12AI | 2.7 | 20 | 19 | 4 | NS |
| | 8.7 | 100 | 7 | 10 | 6 |
| 12AJ | 1.8 | 20 | 19 | 1 | NS |
| | 5.5 | 50 | 15 | 4 | 7 |
| 12AK | 3.7 | 50 | 17 | 3 | NS |
| | 9.1 | 120 | 8 | 10 | 19 |
| 12AL | 0.9 | 30 | 19 | 1 | NS |
| | 4.6 | 50 | 17 | 2 | NS |
| 12AM | 11.1 | 120 | 5 | 11 | 23 |
| 12AN | 1.8 | 50 | 18 | 2 | NS |
| | 5.2 | 80 | 14 | 5 | NS |
| | 8.2 | 110 | 8 | 10 | 1 |
| 12AO | 3.7 | 20 | 18 | 2 | NS |
| | 9.1 | 100 | 5 | 11 | 11 |
| 12AP | 2.7 | 10 | 20 | 1 | NS |
| | 7.3 | 70 | 12 | 6 | NS |
| 12AQ | 2.7 | 20 | 19 | 1 | NS |
| | 7.3 | 70 | 13 | 4 | 16 |
| 12AR | 0.9 | NS ^b | NS | NS | NS |
| | 4.6 | 40 | 18 | 2 | 6 |
| 12AT | 9.4 | 220 | 4 | 12 | 1 |
| CONTROL | 3.7 | 0 | 21 | 0 | NS |
| CONTROL | 7.3 | 0 | 21 | 0 | NS |

^aBy volume.

^bNot sampled.

TABLE 5.16 SOIL GAS CONSTITUENTS IN TUBING CLUSTERS
7 FEBRUARY 1996

| Sample ID | Depth, m | p _G , ppm ^a | p _X , % ^a | p _C , % ^a | p _Y , ppm ^a |
|-----------|----------|-----------------------------------|---------------------------------|---------------------------------|-----------------------------------|
| 12AA | 7.3 | 80 | 10.7 | 7.0 | 51.8 |
| 12AB | 0.9 | 30 | 17.5 | 2.3 | 4.2 |
| | 4.6 | 60 | 15.4 | 3.9 | 23.8 |
| 12AC | 1.8 | 20 | 18.3 | 1.7 | 4.5 |
| | 5.5 | 40 | 15.8 | 3.5 | 19.9 |
| 12AD | 3.7 | 30 | 17.8 | 2.0 | 12.8 |
| | 7.3 | 80 | 10.2 | 7.7 | 58.2 |
| 12AE | 1.8 | 40 | 18 | 1.8 | 4.3 |
| | 5.3 | 60 | 16.4 | 3.3 | 18.2 |
| 12AF | 1.8 | 40 | 18.8 | 1.5 | 3.5 |
| | 5 | 50 | 17.2 | 2.8 | 13.0 |
| 12AG | 0.9 | 20 | 18.8 | 1.4 | 9.8 |
| | 4.6 | 20 | 17.9 | 2.2 | 13.0 |
| 12AH | 3.7 | 40 | 17.1 | 2.7 | 16.8 |
| | 9.1 | 80 | 12.5 | 5.6 | 43.4 |
| 12AI | 2.7 | 30 | 18 | 1.8 | 7.3 |
| | 8.7 | 110 | 6.6 | 9.4 | 68.4 |
| 12AJ | 1.8 | 20 | 18.6 | 1.2 | 7.0 |
| | 5.5 | 80 | 15 | 4.1 | 22.7 |
| 12AK | 3.7 | 60 | 15.8 | 3.1 | 13.8 |
| | 9.1 | 120 | 6.5 | 13.0 | 62.3 |
| 12AL | 0.9 | 40 | 16.9 | 2.3 | 4.8 |
| | 4.6 | 60 | 16.5 | 3.1 | 12.5 |
| 12AO | 3.7 | 20 | 17.8 | 3.6 | 9.5 |
| | 9.1 | 120 | 4.9 | 11.0 | 105.7 |
| 12AP | 2.7 | 40 | 18.7 | 1.3 | 5.2 |
| | 7.3 | 80 | 10.8 | 6.8 | 34.4 |
| 12AQ | 2.7 | 10 | 18.8 | 1.3 | 5.2 |
| | 7.3 | 70 | 12.7 | 5.0 | 51.6 |
| 12AR | 0.9 | 0 | 19.3 | 0.9 | 0 |
| | 4.6 | 10 | 17 | 3.1 | 15.9 |

^aBy volume.

The hydrocarbon reaction rate λ zeros the mean error, while the oxygen flux at the ground surface J_{XO} minimizes the error standard deviation. The cluster 12AN, 12AT, and 12AX data yield the following calibrated values:

TABLE 5.17 SOIL GAS CONSTITUENTS IN TUBING CLUSTERS
13 FEBRUARY 1996

| Sample ID | Depth, m | p _G , ppm ^a | p _X , % ^a | p _C , % ^a | p _Y , ppm ^a |
|-----------|----------|-----------------------------------|---------------------------------|---------------------------------|-----------------------------------|
| 12AA | 7.3 | 50 | 16.9 | 2.7 | 23 |
| 12AB | 0.9 | 50 | 18.4 | 1.8 | 2 |
| | 4.6 | 50 | 19 | 1.1 | 8 |
| 12AC | 1.8 | 0 | 18.2 | 1.5 | 4 |
| | 5.5 | 0 | 17.4 | 2.2 | 15 |
| 12AD | 3.7 | 0 | 18 | 1.8 | 9 |
| | 7.3 | 50 | 13.6 | 5.5 | 54 |
| 12AE | 1.8 | 50 | 17.9 | 1.8 | 4 |
| | 5.3 | 70 | 17.1 | 2.7 | 18 |
| 12AF | 1.8 | 30 | 18.8 | 1.2 | 3 |
| | 5 | 50 | 17.7 | 2.0 | 14 |
| 12AG | 0.9 | 0 | 18.7 | 1.4 | 2 |
| | 4.6 | 0 | 17.9 | 1.9 | 12 |
| 12AH | 3.7 | 50 | 18.2 | 1.8 | 13 |
| | 9.1 | 80 | 19.7 | 0.8 | 6 |
| 12AI | 2.7 | 50 | 18.6 | 1.4 | 4 |
| | 8.7 | 80 | 15 | 4.1 | 40 |
| 12AJ | 1.8 | 30 | 19 | 1.0 | 3 |
| | 5.5 | 30 | 16.9 | 2.6 | 10 |
| 12AK | 3.7 | 70 | 17.3 | 2.2 | 13 |
| | 9.1 | 100 | 13.5 | 5.4 | 44 |
| 12AL | 0.9 | 30 | 17.7 | 2.0 | 3 |
| | 4.6 | 50 | 17.4 | 2.1 | 9 |
| 12AM | 11.1 | NS ^b | NS | NS | NS |
| 12AN | 1.8 | 20 | 18.6 | 1.4 | 1 |
| | 5.2 | 70 | 13.5 | 5.8 | 2 |
| | 8.2 | 40 | 17.1 | 2.7 | 2 |
| 12AO | 3.7 | 0 | 18.6 | 1.2 | 5 |
| | 9.1 | 40 | 16.3 | 3.3 | 34 |
| 12AP | 2.7 | 10 | 19.4 | 0.7 | 2 |
| | 7.3 | 50 | 16 | 3.6 | 14 |
| 12AQ | 2.7 | 0 | 19 | 1.0 | 3 |
| | 7.3 | 40 | 15.5 | 3.5 | 32 |
| 12AR | 0.9 | 0 | 19.7 | 0.7 | 1 |
| | 4.6 | 20 | 18.2 | 1.6 | 12 |
| 12AT | 9.4 | 140 | 9.9 | 8.9 | 5 |
| CONTROL | 3.7 | 0 | 20.8 | 0.1 | 1 |
| CONTROL | 7.3 | 0 | 20.9 | 0.1 | 0 |

^aBy volume.

^bNot sampled.

TABLE 5.18 SOIL GAS CONSTITUENTS IN TUBING CLUSTERS
7 MARCH 1996

| Sample ID | Depth, m | p _G , ppm ^a | p _X , % ^a | p _C , % ^a | p _Y , ppm ^a |
|-----------|----------|-----------------------------------|---------------------------------|---------------------------------|-----------------------------------|
| 12AA | 7.3 | 30 | 18.7 | 1.4 | 15 |
| 12AB | 0.9 | 20 | 18.2 | 1.8 | 3 |
| | 4.6 | 10 | 19 | 1.1 | 7 |
| 12AC | 1.8 | 10 | 18.4 | 1.5 | 4 |
| | 5.5 | 20 | 18.4 | 1.8 | 16 |
| 12AD | 3.7 | 10 | 17.9 | 1.6 | 9 |
| | 7.3 | 50 | 16 | 4.0 | 62 |
| 12AE | 1.8 | 30 | 17.8 | 2.0 | 4 |
| | 5.3 | 40 | 17.5 | 2.2 | 18 |
| 12AF | 1.8 | 40 | 18 | 1.8 | 2 |
| | 5 | 30 | 16.8 | 2.5 | 16 |
| 12AG | 0.9 | 0 | 18.4 | 1.6 | 2 |
| | 4.6 | 20 | 17.8 | 2.2 | 11 |
| 12AH | 3.7 | 40 | 18 | 1.7 | 7 |
| | 9.1 | 10 | 20.3 | 0.5 | 3 |
| 12AI | 2.7 | 30 | 17.9 | 1.9 | 7 |
| | 8.7 | 70 | 14.7 | 4.0 | 57 |
| 12AJ | 1.8 | 20 | 18.5 | 1.4 | 5 |
| | 5.5 | 60 | 15.4 | 3.3 | 23 |
| 12AK | 3.7 | 20 | 17 | 2.6 | 15 |
| | 9.1 | 70 | 13.8 | 1.8 | 61 |
| 12AL | 0.9 | NS ^b | NS | NS | NS |
| | 4.6 | 30 | 16.5 | 2.3 | 13 |
| 12AM | 11.1 | NS | NS | NS | NS |
| 12AN | 1.8 | 60 | 17.3 | 3.8 | 1 |
| | 5.2 | 70 | 14.7 | 7.1 | 3 |
| | 8.2 | 90 | 10.8 | 8.9 | 5 |
| 12AO | 3.7 | 30 | 17.4 | 1.8 | 7 |
| | 9.1 | 50 | 17.4 | 2.2 | 34 |
| 12AP | 2.7 | 20 | 18.4 | 1.4 | 4 |
| | 7.3 | 60 | 15.8 | 3.8 | 50 |
| 12AQ | 2.7 | 20 | 18.4 | 0.1 | 4 |
| | 7.3 | 70 | 14.5 | NS | 47 |
| 12AR | 0.9 | 10 | 19 | 0.8 | 1 |
| | 4.6 | 40 | 17.3 | 1.9 | 17 |
| 12AT | 9.4 | 170 | 8 | 8.9 | 6 |
| CONTROL | 3.7 | 0 | 20.9 | 0.1 | 0 |
| CONTROL | 7.3 | 0 | 20.8 | 0.1 | 0 |

^aBy volume.

^bNot sampled.

TABLE 5.19 SOIL GAS CONSTITUENTS IN TUBING CLUSTERS
17 MARCH 1996

| Sample ID | Depth, m | P_G, ppm^a | P_X, %^a | P_C, %^a | P_Y, ppm^a |
|------------------|-----------------|---------------------------------------|-------------------------------------|-------------------------------------|---------------------------------------|
| 12AA | 7.3 | 40 | 19.2 | 1.2 | 8 |
| 12AB | 0.9 | 50 | 17.8 | 2.3 | 4 |
| | 4.6 | 50 | 18.8 | 1.2 | 7 |
| 12AC | 1.8 | 40 | 18.3 | 1.6 | 5 |
| | 5.5 | 60 | 18.9 | 1.7 | 13 |
| 12AD | 3.7 | 60 | 17.7 | 2.3 | 10 |
| | 7.3 | 90 | 16.9 | 3.8 | 47 |
| 12AE | 1.8 | 50 | 17.5 | 2.0 | 6 |
| | 5.3 | 60 | 18 | 2.0 | 17 |
| 12AF | 1.8 | 50 | 17.5 | 1.6 | 4 |
| | 5 | 60 | 16.2 | 2.8 | 16 |
| 12AG | 0.9 | 50 | 17.7 | 1.8 | 4 |
| | 4.6 | 40 | 17.4 | 2.0 | 3 |
| 12AH | 3.7 | 40 | 17.1 | 2.0 | 12 |
| | 9.1 | 10 | 20.4 | 0.2 | 3 |
| 12AI | 2.7 | 60 | 17.5 | 2.2 | 7 |
| | 8.7 | 70 | 15.3 | 3.6 | 37 |
| 12AJ | 1.8 | 50 | 17.7 | 1.8 | 6 |
| | 5.5 | 60 | 15.1 | 3.7 | 19 |
| 12AK | 3.7 | 50 | 17 | 2.5 | 15 |
| | 9.1 | 60 | 13.8 | 5.0 | 45 |
| 12AL | 0.9 | 50 | 18.8 | 1.3 | 9 |
| | 4.6 | 60 | 16.1 | 2.8 | 13 |
| 12AM | 11.1 | NS ^b | NS | NS | NS |
| 12AN | 1.8 | 30 | 16.3 | 2.5 | 1 |
| | 5.2 | 30 | 13.5 | 5.0 | 3 |
| | 8.2 | 60 | 9.3 | 8.1 | 5 |
| 12AO | 3.7 | 50 | 16.9 | 2.5 | 8 |
| | 9.1 | 50 | 18 | 1.6 | 20 |
| 12AP | 2.7 | 50 | 18 | 1.8 | 5 |
| | 7.3 | 50 | 16.8 | 3.2 | 34 |
| 12AQ | 2.7 | 40 | 17.9 | 1.8 | 5 |
| | 7.3 | 70 | 14.9 | 4.4 | 44 |
| 12AR | 0.9 | 30 | 18.2 | 1.2 | 3 |
| | 4.6 | 40 | 17.1 | 1.8 | 14 |
| 12AT | 9.4 | 130 | 4.3 | 14.0 | 5 |
| CONTROL | 3.7 | 10 | 20.8 | 0.1 | 2 |
| CONTROL | 7.3 | 10 | 20.8 | 0.1 | 1 |

^aBy volume.

^bNot sampled.

TABLE 5.20 SOIL GAS CONSTITUENTS IN TUBING CLUSTERS
4 APRIL 1996

| Sample ID | Depth, m | P _G , ppm ^a | P _X , % ^a | P _C , % ^a | P _Y , ppm ^a |
|-----------|----------|-----------------------------------|---------------------------------|---------------------------------|-----------------------------------|
| 12AA | 7.3 | 0 | 19.8 | 0.7 | 6 |
| 12AB | 0.9 | 10 | 19.3 | 0.9 | 5 |
| | 4.6 | 0 | 19.2 | 0.7 | 5 |
| 12AC | 1.8 | 0 | 18.9 | 1.7 | 5 |
| | 5.5 | 0 | 18.9 | 1.3 | 11 |
| 12AD | 3.7 | 20 | 18.1 | 1.9 | 9 |
| | 7.3 | 30 | 18.2 | 2.3 | 39 |
| 12AE | 1.8 | 20 | 18.4 | 1.8 | 5 |
| | 5.3 | 30 | 17.8 | 2.4 | 5 |
| 12AF | 1.8 | 20 | 18.1 | 2.2 | 3 |
| | 5 | 30 | 16.2 | 3.0 | 16 |
| 12AG | 0.9 | 20 | 18.9 | 1.7 | 3 |
| | 4.6 | 40 | 17.8 | 2.2 | 14 |
| 12AH | 3.7 | 20 | 18.3 | 2.0 | 9 |
| | 9.1 | 0 | 20.5 | 2.5 | 2 |
| 12AI | 2.7 | 20 | 18.5 | 2.0 | 9 |
| | 8.7 | 40 | 16.3 | 4.0 | 29 |
| 12AJ | 1.8 | 20 | 18.5 | 2.4 | 8 |
| | 5.5 | 30 | 15.4 | 4.8 | 21 |
| 12AK | 3.7 | 40 | 17.4 | 1.8 | 13 |
| | 9.1 | 60 | 15 | 2.8 | 34 |
| 12AL | 0.9 | 20 | 18.9 | 1.9 | 6 |
| | 4.6 | 30 | 16.5 | 2.0 | 13 |
| 12AM | 11.1 | NS ^b | NS | NS | NS |
| 12AN | 1.8 | 20 | 15.5 | 4.0 | 2 |
| | 5.2 | 50 | 12.3 | 6.4 | 3 |
| | 8.2 | 80 | 7.1 | 14.0 | 5 |
| 12AO | 3.7 | 20 | 17.4 | 2.9 | 4 |
| | 9.1 | 20 | 18.8 | 2.0 | 17 |
| 12AP | 2.7 | 10 | 18.8 | 2.2 | 6 |
| | 7.3 | 20 | 17.8 | 3.1 | 12 |
| 12AQ | 2.7 | 20 | 18.5 | 2.5 | 7 |
| | 7.3 | 60 | 16.5 | 5.2 | 47 |
| 12AR | 0.9 | 10 | 19.5 | 1.6 | 3 |
| | 4.6 | 30 | 17.7 | 3.3 | 16 |
| 12AT | 9.4 | 200 | 3.9 | 20.0 | 8 |
| CONTROL | 3.7 | 0 | 20.8 | 0.2 | 0 |
| CONTROL | 7.3 | 0 | 20.8 | 0.2 | 0 |

^aBy volume.

^bNot sampled.

TABLE 5.21 SOIL GAS CONSTITUENTS IN TUBING CLUSTERS
5 MAY 1996

| Sample ID | Depth, m | p_G, ppm^a | p_X, %^a | p_Y, ppm^a |
|------------------|-----------------|---------------------------------------|-------------------------------------|---------------------------------------|
| 12AA | 7.3 | 60 | 20.0 | 5 |
| 12AB | 0.9 | 50 | 19.0 | 10 |
| | 4.6 | 40 | 19.0 | 5 |
| 12AC | 1.8 | 60 | 19.0 | 7 |
| | 5.5 | 40 | 19.0 | 9 |
| 12AD | 3.7 | 40 | 19.0 | 11 |
| | 7.3 | 60 | 19.0 | 32 |
| 12AE | 1.8 | 50 | 19.0 | 6 |
| | 5.3 | 60 | 18.0 | 15 |
| 12AF | 1.8 | 50 | 19.0 | 4 |
| | 5 | 60 | 17.0 | 17 |
| 12AG | 0.9 | 40 | 20.0 | 5 |
| | 4.6 | 50 | 19.0 | 14 |
| 12AH | 3.7 | 60 | 19.0 | 9 |
| | 9.1 | 70 | 21.0 | 0 |
| 12AI | 2.7 | 60 | 19.0 | 11 |
| | 8.7 | 70 | 17.0 | 22 |
| 12AJ | 1.8 | 60 | 19.0 | 9 |
| | 5.5 | 80 | 16.0 | 20 |
| 12AK | 3.7 | 50 | 18.0 | 12 |
| | 9.1 | 80 | 15.0 | 31 |
| 12AL | 0.9 | 50 | 19.0 | 9 |
| | 4.6 | 60 | 17.0 | 11 |
| 12AM | 11.1 | 10 | 21.0 | 0 |
| 12AN | 1.8 | 70 | 15.0 | 2 |
| | 5.2 | 80 | 12.0 | 3 |
| | 8.2 | 120 | 6.6 | 4 |
| 12AO | 3.7 | 50 | 18.0 | 12 |
| | 9.1 | 40 | 19.0 | 14 |
| 12AP | 2.7 | 50 | 19.0 | 6 |
| | 7.3 | 60 | 18.0 | 27 |
| 12AQ | 2.7 | 60 | 19.0 | 8 |
| | 7.3 | 50 | 18.0 | 45 |
| 12AR | 0.9 | 40 | 20.0 | 2 |
| | 4.6 | 60 | 18.0 | 16 |
| 12AT | 9.4 | 250 | 2.6 | 7 |
| CONTROL | 3.7 | 20 | 20.9 | 0 |
| CONTROL | 7.3 | 20 | 20.9 | 0 |

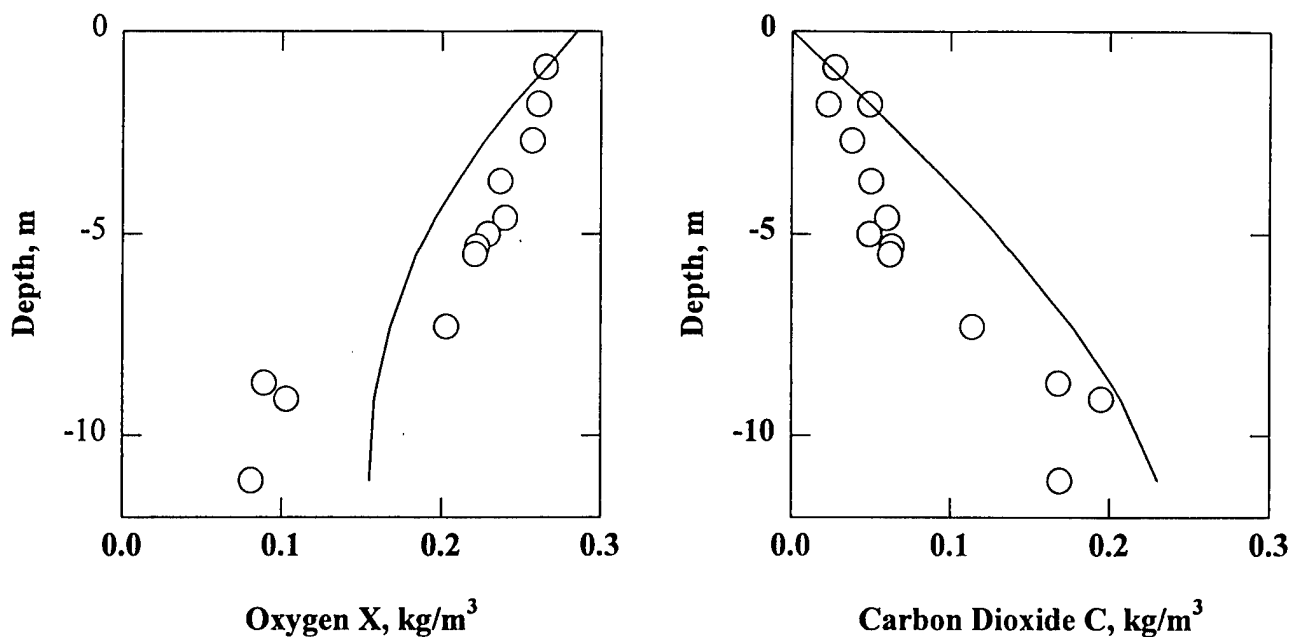
^aBy volume.

TABLE 5.14 SOIL GAS CONSTITUENTS IN TUBING CLUSTERS
16 NOVEMBER 1995

| Sample ID | Depth, m | p _G , ppm ^a | p _X , % ^a | p _C , % ^a |
|-----------|----------|-----------------------------------|---------------------------------|---------------------------------|
| 12AA | 7.3 | 100 | 11 | 7.2 |
| 12AB | 0.9 | 40 | 18.7 | 2.1 |
| | 4.6 | 60 | 15 | 5.6 |
| 12AC | 1.8 | 110 | 19.3 | 0.9 |
| | 5.5 | 140 | 15.5 | 1.9 |
| 12AD | 3.7 | 40 | 17.8 | 2.0 |
| | 7.3 | 80 | 11.7 | 4.3 |
| 12AE | 1.8 | 45 | 19.1 | 1.4 |
| | 5.3 | 80 | 16.4 | 2.8 |
| 12AF | 1.8 | 40 | 19.4 | 0.9 |
| | 5 | 60 | 16.7 | 2.2 |
| 12AG | 0.9 | 40 | 19.5 | 0.7 |
| | 4.6 | 80 | 18.2 | 1.8 |
| 12AH | 3.7 | 10 | 17 | 3.5 |
| | 9.1 | 160 | 9.2 | 9.5 |
| 12AI | 2.7 | 40 | 18.7 | 1.6 |
| | 8.7 | 100 | 7.3 | 7.3 |
| 12AJ | 1.8 | 60 | 19.3 | 0.8 |
| | 5.5 | 60 | 14.4 | 4.2 |
| 12AK | 3.7 | 80 | 16.1 | 3.0 |
| | 9.1 | 100 | 8 | 17.3 |
| 12AL | 0.9 | 60 | 19 | 1.0 |
| | 4.6 | 80 | 16.2 | 2.7 |
| 12AM | 11.1 | 80 | 6.9 | 7.0 |
| 12AN | 1.8 | 80 | 17 | 3.5 |
| | 5.2 | 90 | 12.9 | 6.8 |
| | 8.2 | 100 | 10 | 6.0 |
| 12AO | 3.7 | 60 | 17.7 | 2.2 |
| | 9.1 | 100 | 15.8 | 8.3 |
| 12AP | 2.7 | 40 | 19 | 1.3 |
| | 7.3 | 60 | 11.3 | 5.7 |
| 12AQ | 2.7 | 30 | 18.6 | 1.6 |
| | 7.3 | 80 | 12.6 | 3.9 |
| 12AR | 0.9 | 20 | 19.8 | 0.7 |
| | 4.6 | 60 | 16.3 | 3.0 |
| 12AT | 9.4 | NS ^b | NS | NS |
| CONTROL | 3.7 | 0 | 20.7 | 0.0 |
| CONTROL | 7.3 | 0 | 20.7 | 0.0 |

^aBy volume.

^bNot sampled.



Note: Time averaged data.

Figure 5.10 Observed (Symbols) and Calibrated (Curves) Ambient Soil Gas Oxygen and Carbon Dioxide in Clusters 12AN, 12AT, and 12AX

**TABLE 5.22 (Continued) SOIL GAS CONSTITUENTS IN TUBING CLUSTERS
15 JUNE 1996**

| Sample ID | Depth, m | p_G , ppm ^a | p_X , % ^a | p_Y , ppm ^a |
|-----------|----------|--------------------------|------------------------|--------------------------|
| 12AU | 11 | NS ^b | NS | NS |
| 12AV | 10.9 | 0 | 20.9 | 0 |
| 12AW | 10.8 | 0 | 20.9 | 0 |
| 12AX | 3 | 80 | 15.0 | 2 |
| | 9.3 | 100 | 13.0 | 3 |
| 12AZ | 10.7 | 120 | 20.9 | 4 |
| 12BA | 11 | 120 | 20.9 | 12 |

^aBy volume.

^bNot sampled.

$$\lambda = 3.34 \times 10^{-8} \text{ s}^{-1} \quad (\text{ambient}) \quad (5.31a)$$

$$J_{XO} = 6.62 \times 10^{-8} \frac{\text{kg}}{\text{m}^2 \cdot \text{s}} \quad (5.31b)$$

The combined error standard deviation is 15%, a reasonable accuracy in view of the scatter

**TABLE 5.24 SOIL GAS TRICHLOROETHYLENE IN TUBING CLUSTERS
9 AUGUST 1996**

| Sample ID | Depth, m | p _y , ppm ^a | Sample ID | Depth, m | p _y , ppm ^a |
|-----------|----------|-----------------------------------|-----------|----------|-----------------------------------|
| 12AA | 7.3 | 0 | 12AM | 11.1 | 0 |
| 12AB | 0.9 | 7 | 12AN | 1.8 | 2 |
| | 4.6 | 0 | | 5.5 | 1 |
| 12AC | 1.8 | 4 | | 9.1 | 0 |
| | 5.5 | 8 | 12AO | 3.7 | 25 |
| 12AD | 3.7 | 11 | | 9.1 | 5 |
| | 7.3 | 27 | 12AP | 2.7 | 11 |
| 12AE | 1.8 | 1 | | 7.3 | 43 |
| | 5.3 | 18 | 12AQ | 2.7 | 25 |
| 12AF | 1.8 | 6 | | 7.3 | 126 |
| | 5 | 60 | 12AR | 0.9 | 7 |
| 12AG | 0.9 | 9 | | 4.6 | 44 |
| | 4.6 | 8 | 12AT | 9.4 | 5 |
| 12AH | 3.7 | 8 | 12AU | 11 | 0 |
| | 9.1 | 0 | 12AV | 10.9 | 0 |
| 12AI | 2.7 | 10 | 12AW | 10.8 | 0 |
| | 8.7 | 10 | 12AX | 3 | 0 |
| 12AJ | 1.8 | 8 | | 9.3 | 0 |
| | 5.5 | 51 | 12AZ | 10.7 | 0 |
| 12AK | 3.7 | 12 | 12BA | 11 | 0 |
| | 9.1 | 52 | CONTROL | 3.7 | 0 |
| 12AL | 0.9 | 8 | CONTROL | 7.3 | 0 |
| | 4.6 | 17 | | | |

^aBy volume.

$$\delta_{GM} = \frac{1}{N} \sum_N \delta_G \quad (5.32b)$$

$$\sigma_G = \sqrt{\frac{1}{N} \sum_N \delta_G^2 - \delta_{GM}^2} \quad (5.32c)$$

Figure 5.11 shows the results of the total hydrocarbon calibration at clusters 12AN, 12AT, and 12AX, based on the following parameter values:

$$G_F = 9.36 \times 10^{-4} \frac{\text{kg}}{\text{m}^3} \quad (\text{ambient}) \quad (5.33a)$$

$$b_F = 11.76 \text{m} \quad (12\text{AN}, 12\text{AT}, 12\text{AX}) \quad (5.33b)$$

TABLE 5.25 SOIL GAS CONSTITUENTS IN TUBING CLUSTERS
20 AUGUST 1996

| Sample ID | Depth, m | p _G , ppm ^a | p _X , % ^a | p _C , % ^a | p _Y , ppm ^a |
|-----------|----------|-----------------------------------|---------------------------------|---------------------------------|-----------------------------------|
| 12AD | 3.7 | 50 | 18.7 | 1.9 | 16 |
| | 7.3 | 50 | 19.0 | 1.0 | 19 |
| 12AH | 9.1 | 350 | 18.6 | 0.3 | 133 |
| 12AI | 2.7 | 20 | 18.8 | 1.8 | 0 |
| | 8.7 | 80 | 15.8 | 1.8 | 51 |
| 12AK | 3.7 | 100 | 18.8 | 0.3 | 11 |
| | 9.1 | 120 | 18.6 | 0.2 | 31 |
| 12AM | 11.1 | 500 | 18.5 | 0.2 | 120 |
| 12AQ | 2.7 | 60 | 18.9 | 2.2 | 14 |
| | 7.3 | 60 | 18.7 | 1.4 | 34 |
| 12AR | 0.9 | 40 | 19.1 | 1.4 | 5 |
| | 4.6 | 50 | 18.3 | 1.7 | 17 |
| 12AV | 10.9 | 300 | 18.6 | 0.8 | 120 |
| 12AW | 10.8 | 500 | 19.3 | 0.2 | 157 |
| 12AZ | 10.7 | 220 | 18.9 | 0.19 | 104 |
| 12BA | 11 | 320 | 19.1 | 0.21 | 115 |

^aBy volume.

We note considerable scatter in the fit, evidenced by the σ_G value of 45%. Nonetheless, the use of a common reaction rate across the oxygen, carbon dioxide, and total hydrocarbon ambient data sets endorses the physical validity of the calibration.

We test the calibrated steady ambient model reaction rate (Equation 5.31a) and oxygen flux (Equation 5.31b) against the ambient vapor probe data (VP1, VP2, and VP3), with the observations averaged at each depth. Figure 5.12 summarizes the results: the combined mean error is 12%, suggesting a modest overprediction of the probe data. The error standard deviation is 31%. We note a systematic overprediction with depth--an error that may be partially due to our use of fall probe data in a time averaged model. In this regard, the soil temperature is warmer than average in the fall (Figure 5.1), giving rise to higher diffusivities in this period. A flatter gradient would accordingly be needed to sustain the same flux. The ambient vapor probe hydrocarbon data are calibrated with a higher fringe concentration than the ambient cluster data, as suggested by Figure 5.13:

$$G_F = 3.66 \times 10^{-3} \frac{\text{kg}}{\text{m}^3} \quad (\text{ambient}) \quad (5.34a)$$

$$b_F = 13.15\text{m} \quad (\text{vapor probes}) \quad (5.32b)$$

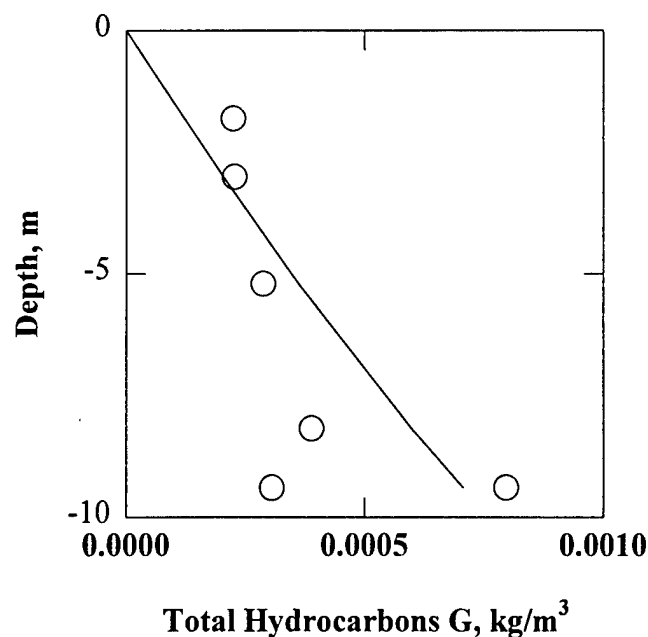
We sampled the clusters above the injection points on 26 October 1995, 16 November 1995, and

TABLE 5.23 SOIL GAS CONSTITUENTS IN TUBING CLUSTERS

15 JULY 1996

| Sample ID | Depth, m | p _G , ppm ^a | p _X , % ^a | p _Y , ppm ^a |
|-----------|----------|-----------------------------------|---------------------------------|-----------------------------------|
| 12AA | 7.3 | 0 | 20.0 | 0.1 |
| 12AB | 0.9 | 20 | 19.0 | 6 |
| | 4.6 | 0 | 20.0 | 0.3 |
| 12AC | 1.8 | 20 | 19.0 | 5 |
| | 5.5 | 40 | 17.0 | 7 |
| 12AD | 3.7 | 20 | 19.0 | 21 |
| | 7.3 | 20 | 20.0 | 51 |
| 12AE | 1.8 | 20 | 19.0 | 16 |
| | 5.3 | 20 | 19.0 | 23 |
| 12AF | 1.8 | 40 | 19.0 | 7 |
| | 5 | 40 | 19.0 | 67 |
| 12AG | 0.9 | 40 | 19.0 | 12 |
| | 4.6 | 40 | 19.0 | 54 |
| 12AH | 3.7 | 40 | 19.0 | 9 |
| | 9.1 | 0 | 20.9 | 0 |
| 12AI | 2.7 | 20 | 19.0 | 5 |
| | 8.7 | 20 | 17.0 | 10 |
| 12AJ | 1.8 | 20 | 19.0 | 5 |
| | 5.5 | 40 | 16.0 | 22 |
| 12AK | 3.7 | 40 | 18.0 | 8 |
| | 9.1 | 60 | 16.0 | 37 |
| 12AL | 0.9 | 20 | 19.0 | 6 |
| | 4.6 | 40 | 17.0 | 20 |
| 12AM | 11.1 | 0 | 20.9 | 0 |
| 12AN | 1.8 | 40 | 17.0 | 1 |
| | 5.2 | 60 | 16.0 | 1 |
| | 8.2 | 60 | 15.0 | 1 |
| 12AO | 3.7 | 40 | 18.0 | 15 |
| | 9.1 | 60 | 20.0 | 1 |
| 12AP | 2.7 | 20 | 19.0 | 2 |
| | 7.3 | 10 | 19.0 | 15 |
| 12AQ | 2.7 | 40 | 19.0 | 11 |
| | 7.3 | 40 | 19.0 | 95 |
| 12AR | 0.9 | 50 | 18.0 | 2 |
| | 4.6 | 30 | 19.0 | 12 |
| 12AT | 9.4 | 200 | 8.2 | 2 |
| CONTROL | 3.7 | 20 | 20.9 | 0 |
| CONTROL | 7.3 | 20 | 20.9 | 0 |

^aBy volume.



Note: Time averaged data.

Figure 5.11 Observed (Symbols) and Calibrated (Curves) Ambient Soil Gas Total Hydrocarbons in Clusters 12AN, 12AT, and 12AX

**TABLE 5.23 (Continued) SOIL GAS CONSTITUENTS IN TUBING CLUSTERS
15 JULY 1996**

| Sample ID | Depth, m | p_G , ppm ^a | p_X , % ^a | p_Y , ppm ^a |
|-----------|----------|--------------------------|------------------------|--------------------------|
| 12AU | 11 | 0 | 20.9 | 0 |
| 12AV | 10.9 | 0 | 20.9 | 0 |
| 12AW | 10.8 | 0 | 20.9 | 0 |
| 12AX | 3 | 40 | 16.0 | 0 |
| | 9.3 | 60 | 15.0 | 3 |
| 12AZ | 10.7 | 40 | 19.0 | 0 |
| 12BA | 11 | 0 | 20.9 | 0 |

^aBy volume.

inherent in field sampling under adverse conditions.

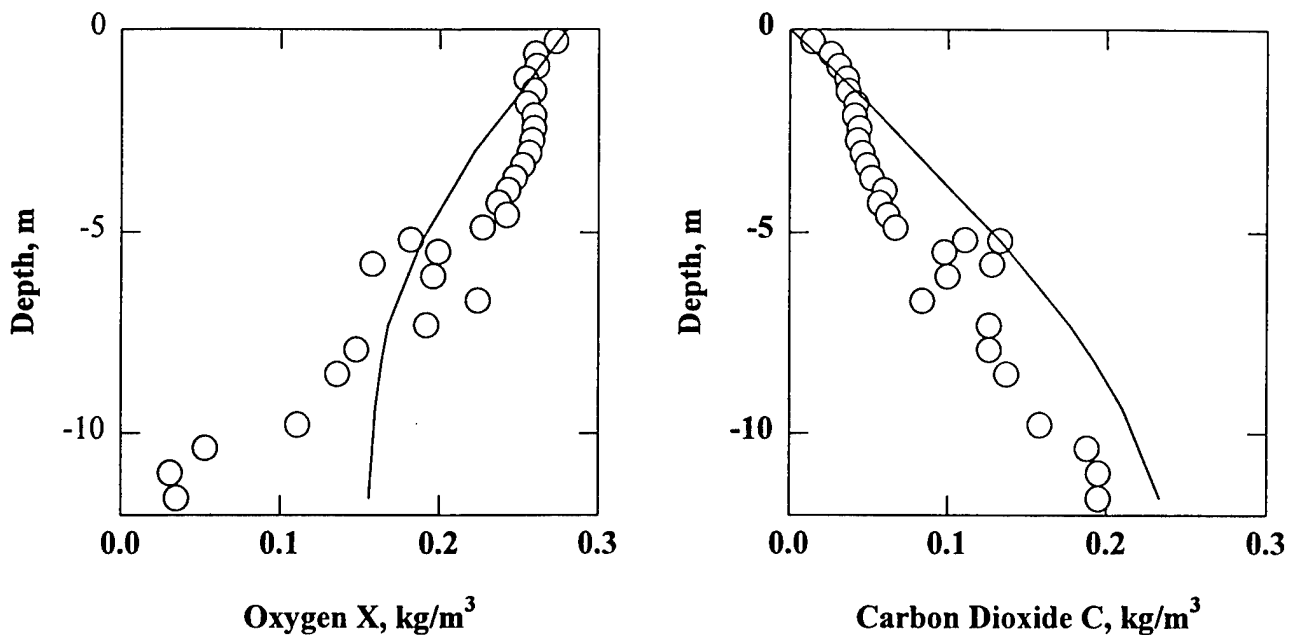
Since the degradation rate are specified, the total hydrocarbon profiles may be calibrated with the capillary fringe boundary concentration G_0 and the depth z_0 to the origin of clusters 12AN, 12AX, and 12AT. These two parameters drive a Fibonacci search designed to optimize the hydrocarbon vapor error statistics δ_{GM} and σ_G defined in the usual fashion

$$\delta_G = \frac{G(\text{measured}) - G(\text{predicted})}{G(\text{predicted})} \quad (5.32a)$$

TABLE 5.26 SOIL GAS CONSTITUENTS IN TUBING CLUSTERS
13 OCTOBER 1996

| Sample ID | Depth, m | p _G , ppm ^a | p _X , % ^a | p _Y , ppm ^a |
|-----------|----------|-----------------------------------|---------------------------------|-----------------------------------|
| 12AA | 7.3 | 60 | 17.3 | 12.9 |
| 12AB | 0.9 | 60 | 20 | 2.1 |
| | 4.6 | 60 | 18.7 | 7.8 |
| 12AC | 1.8 | 40 | 19.8 | 1.5 |
| | 5.5 | 20 | 18.6 | 11.1 |
| 12AD | 3.7 | 60 | 19.1 | 10.3 |
| | 7.3 | 60 | 17.9 | 17.8 |
| 12AE | 1.8 | 60 | 19.7 | 3.4 |
| | 5.3 | 60 | 18.6 | 11.1 |
| 12AF | 1.8 | 60 | 19.6 | 3.0 |
| | 5 | 60 | 18.3 | 13.2 |
| 12AG | 0.9 | 60 | 19.8 | 2.9 |
| | 4.6 | 60 | 19 | 13.3 |
| 12AH | 3.7 | 60 | 19.1 | 6.7 |
| | 9.1 | 40 | 16.1 | 10.3 |
| 12AI | 2.7 | 60 | 19.6 | 4.3 |
| | 8.7 | 80 | 13.6 | 12.3 |
| 12AJ | 1.8 | 60 | 19.9 | 2.0 |
| | 5.5 | 80 | 17 | 12.3 |
| 12AK | 3.7 | 60 | 18.9 | 6.8 |
| | 9.1 | 80 | 14.9 | 13.4 |
| 12AL | 0.9 | 40 | 20 | 0.0 |
| | 4.6 | 60 | 18.5 | 7.2 |
| 12AM | 11.1 | 80 | 16 | 10.9 |
| 12AN | 1.8 | 100 | 18.8 | 0.2 |
| | 5.2 | 100 | 16.7 | 2.0 |
| | 8.2 | 120 | 15.2 | 3.0 |
| 12AO | 3.7 | 80 | 19.1 | 8.1 |
| | 9.1 | 60 | 15.4 | 11.2 |
| 12AP | 2.7 | 60 | 19.4 | 3.4 |
| | 7.3 | 60 | 17.4 | 19.1 |
| 12AQ | 2.7 | 80 | 19.2 | 7.7 |
| | 7.3 | 80 | 18.2 | 32.9 |
| 12AR | 0.9 | 60 | 19.9 | 1.1 |
| | 4.6 | 60 | 18.9 | 14.0 |
| 12AT | 9.4 | 200 | 12.4 | 6.4 |
| CONTROL | 3.7 | 20 | 20.7 | 0 |
| CONTROL | 7.3 | 20 | 20.7 | 0 |

^aBy volume.



Note: Vapor probe data are averaged at each depth.

Figure 5.12 Observed (Symbols) and Calibrated (Curves) Ambient Soil Gas Oxygen and Carbon Dioxide in VP1, VP2, and VP3

**TABLE 5.26 (Continued) SOIL GAS CONSTITUENTS IN TUBING CLUSTERS
13 OCTOBER 1996**

| Sample ID | Depth, m | p_G , ppm ^a | p_X , % ^a | p_Y , ppm ^a |
|-----------|----------|--------------------------|------------------------|--------------------------|
| 12AU | 11 | 80 | 15.4 | 9.3 |
| 12AV | 10.9 | 60 | 15.1 | 10.1 |
| 12AW | 10.8 | 60 | 16.6 | 11.7 |
| 12AX | 3 | 80 | 16.7 | 1.0 |
| | 9.3 | 100 | 14.5 | 1.5 |
| 12AZ | 10.7 | 60 | 15.6 | 12.7 |
| 12BA | 11 | 60 | 16.5 | 12.5 |

^aBy volume.

16 January 1996 before inducing an air flow in the subsurface. We average clusters over the three dates and at each depth to generate a third ambient data base for supplemental model testing and calibration:

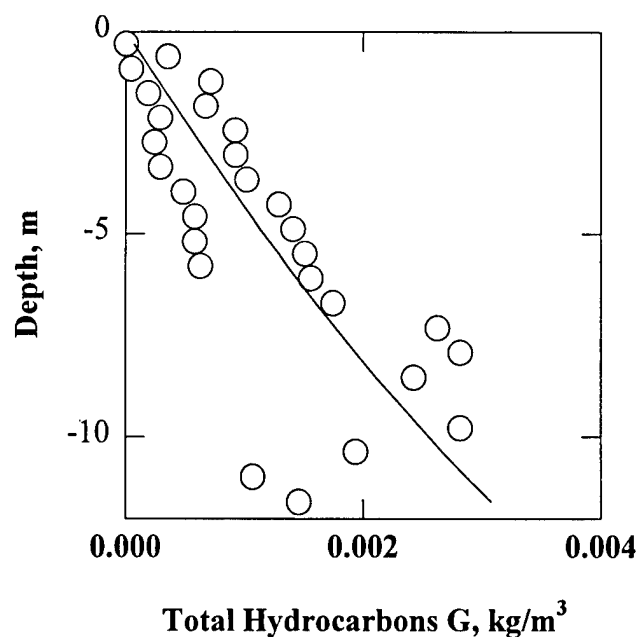
- Depth 0.9 m-12AB, 12AG, 12AL, and 12AR
- Depth 1.8 m-12AC, 12AE, 12AF, and 12AJ
- Depth 2.7 m-12AI, 12AP, and 12AQ
- Depth 3.7 m-12AD, 12AH, 12AK, and 12AO
- Depth 4.6 m-12AB, 12AG, 12AL and 12AR
- Depth 5.0 m-12AF

**TABLE 5.27 SOIL GAS CONSTITUENTS IN TUBING CLUSTERS
7 NOVEMBER 1996**

| Sample ID | Depth, m | p _G , ppm ^a | p _X , % ^a | p _Y , ppm ^a |
|-----------|----------|-----------------------------------|---------------------------------|-----------------------------------|
| 12AA | 7.3 | 0 | 20.1 | 7 |
| 12AB | 0.9 | 20 | 20.3 | 3 |
| | 4.6 | 0 | 20.0 | 9 |
| 12AC | 1.8 | 0 | 20.0 | 4 |
| | 5.5 | 0 | 19.8 | 14 |
| 12AD | 3.7 | 0 | 19.4 | 10 |
| | 7.3 | 0 | 19.1 | 21 |
| 12AE | 1.8 | 0 | 20.1 | 0 |
| | 5.3 | 0 | 19.6 | 15 |
| 12AF | 1.8 | 0 | 20.0 | 4 |
| | 5 | 10 | 19.2 | 16 |
| 12AG | 0.9 | 0 | 20.0 | 3 |
| | 4.6 | 0 | 20.3 | 17 |
| 12AH | 3.7 | 0 | 19.7 | 7 |
| | 9.1 | 0 | 20.6 | 7 |
| 12AI | 2.7 | 0 | 20.3 | 3 |
| | 8.7 | 30 | 17.8 | 17 |
| 12AJ | 1.8 | 0 | 20.4 | 1 |
| | 5.5 | 30 | 18.4 | 17 |
| 12AK | 3.7 | 0 | 19.8 | 7 |
| | 9.1 | 20 | 18.7 | 2 |
| 12AL | 0.9 | 0 | 20.4 | 2 |
| | 4.6 | 0 | 19.8 | NS ^b |
| 12AM | 11.1 | 0 | 20.7 | 13 |
| 12AN | 1.8 | 10 | 18.5 | 1 |
| | 5.2 | 10 | 18.5 | 2 |
| | 8.2 | 60 | 15.0 | 5 |
| 12AO | 3.7 | 0 | 19.1 | 3 |
| | 9.1 | 0 | 18.3 | 17 |
| 12AP | 2.7 | 0 | 19.7 | NS |
| | 7.3 | 10 | 18.7 | 21 |
| 12AQ | 2.7 | 0 | 19.4 | 9 |
| | 7.3 | 30 | 18.3 | 40 |
| 12AR | 0.9 | 0 | 20.0 | 2 |
| | 4.6 | 20 | 19.0 | 19 |
| 12AT | 9.4 | 100 | 13.5 | 2 |
| CONTROL | 3.7 | 0 | 20.8 | 0 |
| CONTROL | 7.3 | 0 | 20.8 | 0 |

^aBy volume.

^bNot sampled.



Note: Vapor probe data are averaged at each depth.

Figure 5.13 Observed (Symbols) and Calibrated (Curves) Ambient Soil Gas Total Hydrocarbon in VP1 and VP3

**TABLE 5.27 (Continued) SOIL GAS CONSTITUENTS IN TUBING CLUSTERS
7 NOVEMBER 1996**

| Sample ID | Depth, m | p_G , ppm ^a | p_X , % ^a | p_Y , ppm ^a |
|-----------|----------|--------------------------|------------------------|--------------------------|
| 12AU | 11 | 20 | 20.7 | 13 |
| 12AV | 10.9 | 260 | 20.7 | 93 |
| 12AW | 10.8 | 0 | 20.7 | 8 |
| 12AX | 3 | NS ^b | NS | 2 |
| | 9.3 | 60 | 14.5 | 4 |
| 12AZ | 10.7 | 0 | 20.7 | 5 |
| 12BA | 11 | 0 | 20.7 | 7 |

^aBy volume.

^bNot sampled.

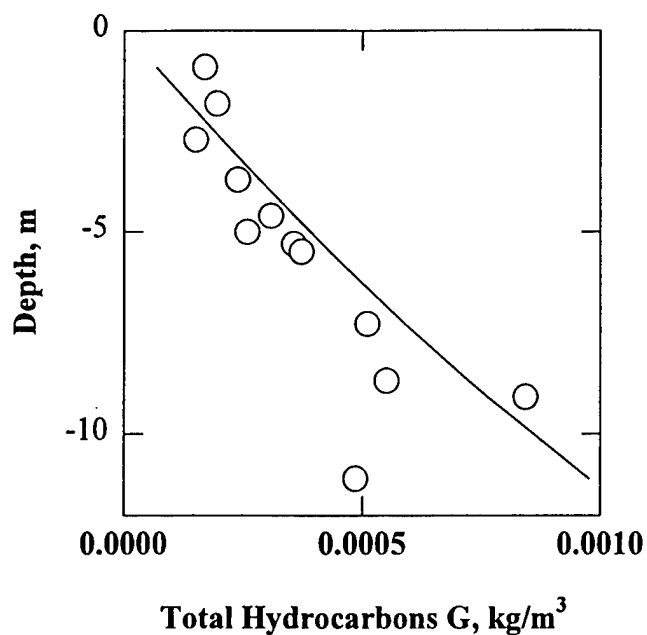
- Depth 5.3 m-12AE
- Depth 5.5m-12AC and 12AJ
- Depth 7.3 m-12AA, 12AD, 12AP, and 12AQ
- Depth 8.7 m-12AI
- Depth 9.1 m-12AH, 12AK, and 12AO
- Depth 11.1 m-12AM

TABLE 5.29 SOIL GAS CONSTITUENTS IN TUBING CLUSTERS
19 DECEMBER 1996

| Sample ID | Depth, m | p _G , ppm ^a | p _X , % ^a | p _V , ppm ^a |
|-----------|----------|-----------------------------------|---------------------------------|-----------------------------------|
| 12AA | 7.3 | 0 | 20.5 | 0.7 |
| 12AB | 0.9 | 0 | 20.5 | 1 |
| | 4.6 | 0 | 20.3 | 0.7 |
| 12AC | 1.8 | 0 | 20.5 | 0.5 |
| | 5.5 | 10 | 20.3 | 0.8 |
| 12AD | 3.7 | 10 | 20.2 | 1.3 |
| | 7.3 | 20 | 20 | 1.5 |
| 12AE | 1.8 | 10 | 20.4 | 0.5 |
| | 5.3 | 10 | 19.9 | 0.5 |
| 12AF | 1.8 | 10 | 20.2 | 1.2 |
| | 5 | 10 | 19.3 | 1.8 |
| 12AG | 0.9 | 0 | 20.6 | 0.6 |
| | 4.6 | 10 | 20.2 | 1.3 |
| 12AH | 3.7 | 0 | 20 | 1.2 |
| | 9.1 | 0 | 20.8 | 0.3 |
| 12AI | 2.7 | 0 | 20.2 | 1 |
| | 8.7 | 10 | 17.8 | 1.8 |
| 12AJ | 1.8 | 0 | 20.1 | 0.7 |
| | 5.5 | 20 | 18.2 | 2.4 |
| 12AK | 3.7 | 0 | 19.7 | 1 |
| | 9.1 | 10 | 18.3 | 1.8 |
| 12AL | 0.9 | 0 | 20.2 | 0.3 |
| | 4.6 | 10 | 19.3 | 1.5 |
| 12AM | 11.1 | NS ^b | NS | NS |
| 12AN | 1.8 | 30 | 17.8 | 5.3 |
| | 5.2 | 20 | 17.9 | 4 |
| | 8.2 | 40 | 15.4 | 6.3 |
| 12AO | 3.7 | 10 | 19.3 | 2.2 |
| | 9.1 | 20 | 19 | 2 |
| 12AP | 2.7 | 0 | 20.3 | 1.3 |
| | 7.3 | 20 | 19.3 | 1.2 |
| 12AQ | 2.7 | 0 | 20.1 | 1.3 |
| | 7.3 | 10 | 19.1 | 2.2 |
| 12AR | 0.9 | 0 | 20.4 | 0.5 |
| | 4.6 | 20 | 19.7 | 1.6 |
| 12AT | 9.4 | 110 | 13.6 | 8 |
| CONTROL | 3.7 | 0 | 20.8 | 0.2 |
| CONTROL | 7.3 | NS | NS | NS |

^aBy volume.

^bNot sampled.



Note: Cluster data are averaged at each depth.

**Figure 5.15 Observed (Symbols) and Calibrated (Curves) Ambient Soil Gas Total Hydrocarbons in 12AA-12AM, 12AO-12AR, 12AU-12AW, 12AZ, and 12BA
26 October 1995-16 January 1996**

**TABLE 5.29 (Continued) SOIL GAS CONSTITUENTS IN TUBING CLUSTERS
19 DECEMBER 1996**

| Sample ID | Depth, m | p_G , ppm ^a | p_X , % ^a | p_Y , ppm ^a |
|-----------|----------|--------------------------|------------------------|--------------------------|
| 12AU | 11 | 0 | 20.8 | 0.4 |
| 12AV | 10.9 | 0 | 20.9 | 0.2 |
| 12AW | 10.8 | 10 | 20.8 | 0.4 |
| 12AX | 3 | 10 | 18.5 | 3.5 |
| | 9.3 | 20 | 14.8 | 7.4 |
| 12AZ | 10.7 | 0 | 20.9 | 0.2 |
| 12BA | 11 | NS ^b | NS | NS |

^aBy volume.

^bNot sampled.

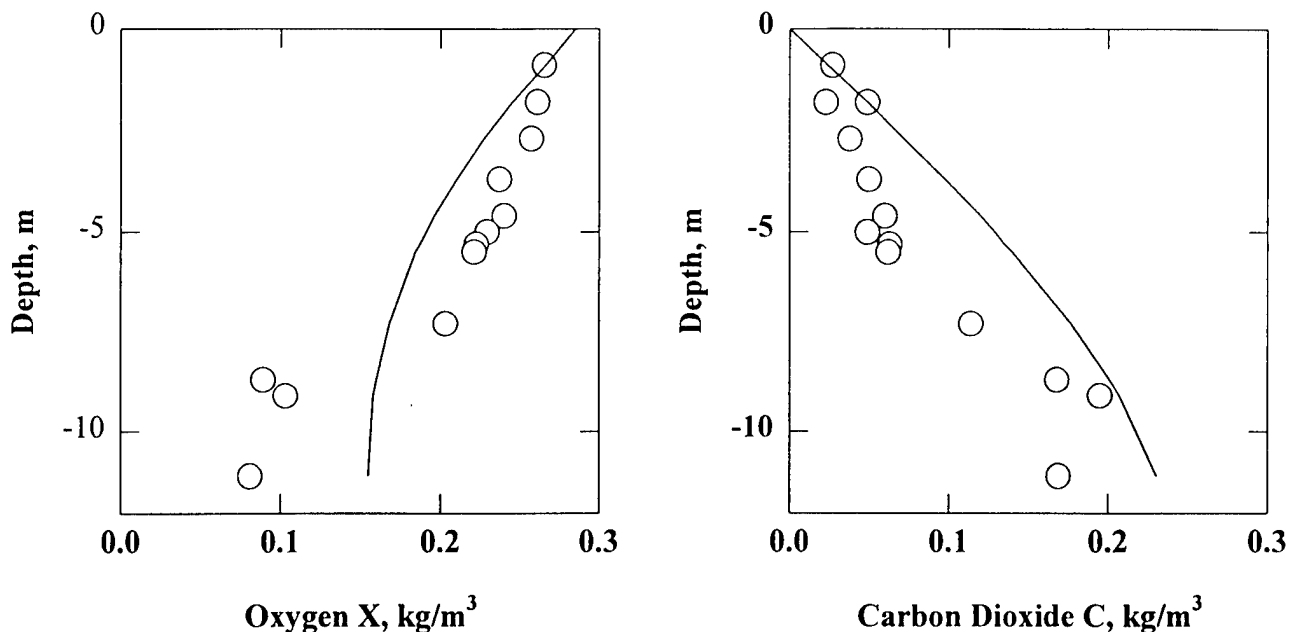
$$G_F = 1.39 \times 10^{-3} \frac{\text{kg}}{\text{m}^3} \quad (\text{ambient}) \quad (5.35a)$$

$$b_F = 14.29\text{m} \quad (\text{fall clusters}) \quad (5.35b)$$

**TABLE 5.28 SOIL GAS CONSTITUENTS IN TUBING CLUSTERS
21 NOVEMBER 1996**

| Sample ID | Depth, m | p _G , ppm ^a | p _X , % ^a | p _V , ppm ^a |
|-----------|----------|-----------------------------------|---------------------------------|-----------------------------------|
| 12AA | 7.3 | 0 | 20.7 | 3 |
| 12AB | 0.9 | 0 | 20.5 | 2 |
| | 4.6 | 0 | 20.3 | 5 |
| 12AC | 1.8 | 0 | 20.5 | 3 |
| | 5.5 | 0 | 20.3 | 10 |
| 12AD | 3.7 | 10 | 20.1 | 11 |
| | 7.3 | 30 | 19.9 | 21 |
| 12AE | 1.8 | 0 | 20.4 | 3 |
| | 5.3 | 10 | 20.1 | 12 |
| 12AF | 1.8 | 20 | 20.9 | 1 |
| | 5 | 50 | 20.1 | 14 |
| 12AG | 0.9 | 0 | 20.3 | 3 |
| | 4.6 | 20 | 19.8 | 11 |
| 12AH | 3.7 | 0 | 20.9 | 6 |
| | 9.1 | 0 | 20.6 | 2 |
| 12AI | 2.7 | 20 | 20.2 | 3 |
| | 8.7 | 40 | 18.8 | 10 |
| 12AJ | 1.8 | 0 | 20.2 | 2 |
| | 5.5 | 40 | 19.4 | 11 |
| 12AK | 3.7 | 20 | 20 | 6 |
| | 9.1 | 20 | 18.8 | 10 |
| 12AL | 0.9 | 0 | 20.3 | 1 |
| | 4.6 | 0 | 19.9 | 6 |
| 12AM | 11.1 | 10 | 20.8 | 11 |
| 12AN | 1.8 | 20 | 18.3 | 2 |
| | 5.2 | 40 | 16.3 | 2 |
| | 8.2 | 60 | 15.7 | 3 |
| 12AO | 3.7 | 20 | 19.3 | 9 |
| | 9.1 | 30 | 19.6 | 9 |
| 12AP | 2.7 | 0 | 19.9 | 4 |
| | 7.3 | 20 | 19.9 | 19 |
| 12AQ | 2.7 | 0 | 20 | 7 |
| | 7.3 | 40 | 19.5 | 32 |
| 12AR | 0.9 | 0 | 20.4 | 1 |
| | 4.6 | 20 | 19.8 | 14 |
| 12AT | 9.4 | 240 | 14.4 | 8 |
| CONTROL | 3.7 | 0 | 20.6 | 0 |
| CONTROL | 7.3 | 0 | 20.7 | 0 |

^aBy volume.



Note: Cluster data are averaged at each depth.

**Figure 5.14 Observed (Symbols) and Calibrated (Curves) Ambient Soil Gas Oxygen and Carbon Dioxide in 12AA-12AM, 12AO-12AR, 12AU-12AW, 12AZ, and 12BA
26 October 1995-16 January 1996**

**TABLE 5.28 (Continued) SOIL GAS CONSTITUENTS IN TUBING CLUSTERS
21 NOVEMBER 1996**

| Sample ID | Depth, m | p_G , ppm ^a | p_X , % ^a | p_Y , ppm ^a |
|-----------|----------|--------------------------|------------------------|--------------------------|
| 12AU | 11 | 0 | 20.8 | 5 |
| 12AV | 10.9 | 40 | 20.7 | 19 |
| 12AW | 10.8 | 0 | 20.6 | 8 |
| 12AX | 3 | 60 | 15.8 | 1 |
| | 9.3 | 60 | 15.7 | 2 |
| 12AZ | 10.7 | 0 | 20.6 | 4 |
| 12BA | 11 | 0 | 20.7 | 8 |

^aBy volume.

Figure 5.14 displays the ambient tubing cluster data and calibration for oxygen and carbon dioxide, which feature a combined mean error of 20% and a combined error standard deviation of 28%. The figure is similar to its vapor probe counterpart in Figure 5.12--both data sets were taken in the fall only, subject to higher diffusivities and flatter gradients of vapor. The corresponding total hydrocarbon vapor concentration and water table depth are

TABLE 5.30 HELIUM TRACER PRESSURES p_H IN TUBING CLUSTERS^a

| Sample ID | Depth, m | 13Feb96 6 days | 21Feb96 14 days | 7Nov96 14 days | 20Nov96 27 days |
|-----------|----------|-------------------|--------------------|-------------------|--------------------|
| 12AA | 7.3 | NS ^b | 1790 | 3355 | 4473 |
| 12AB | 0.9 | 144 | 232 | 483 | 1234 |
| | 4.6 | 83 | 422 | 1839 | 3084 |
| 12AC | 1.8 | 67 | 144 | 65 | 675 |
| | 5.5 | 138 | 568 | 1393 | 2693 |
| 12AD | 3.7 | 39 | 148 | 523 | 1377 |
| | 7.3 | 219 | 948 | 2436 | 3896 |
| 12AE | 1.8 | 48 | 146 | 109 | 905 |
| | 5.3 | 82 | 296 | 1121 | 2292 |
| 12AF | 1.8 | 33 | 26 | 60 | 289 |
| | 5 | 22 | 59 | 181 | 643 |
| 12AG | 0.9 | 17 | 64 | 85 | 376 |
| | 4.6 | 47 | 127 | 398 | 781 |
| 12AH | 3.7 | 65 | 219 | 700 | 1499 |
| | 9.1 | 808 | 2433 | 307 | 5174 |
| 12AI | 2.7 | 43 | 101 | 322 | 756 |
| | 8.7 | 391 | 1114 | 3447 | 4431 |
| 12AJ | 1.8 | 22 | 59 | 145 | 415 |
| | 5.5 | 97 | 94 | 469 | 12041 |
| 12AK | 3.7 | 88 | 332 | 1110 | 2151 |
| | 9.1 | 473 | 1416 | 148 | 4732 |
| 12AL | 0.9 | 72 | 77 | 432 | 997 |
| | 4.6 | 53 | 134 | NS | 1113 |
| 12AM | 11.1 | NS | NS | 5957 | 8962 |
| 12AO | 3.7 | 18 | 35 | 470 | 533 |
| | 9.1 | 432 | 1263 | 3465 | 4831 |
| 12AP | 2.7 | 66 | 54 | 179 | 454 |
| | 7.3 | 163 | 545 | 2346 | 3701 |
| 12AQ | 2.7 | 0 | 31 | NS | 472 |
| | 7.3 | 48 | 213 | 1377 | 2780 |
| 12AR | 0.9 | 13 | 73 | 64 | 288 |
| | 4.6 | 44 | 108 | 608 | 1766 |
| 12AU | 9.4 | NS | NS | 5886 | 6940 |
| 12AV | 11 | NS | NS | 2239 | 9726 |
| 12AW | 10.9 | NS | NS | 5183 | 5493 |
| 12AZ | 9.3 | NS | NS | 4974 | 5783 |
| 12BA | 10.7 | NS | NS | 4968 | 5769 |

^a ppm by volume.

^b Not sampled.

TABLE 5.31 SOIL GAS CONSTITUENTS IN VAPOR PROBE VP1

| Depth, m | p _G , ppm ^a | p _X , % ^a | p _C , % ^a |
|----------|-----------------------------------|---------------------------------|---------------------------------|
| 0 | 40 | 20.8 | 0 |
| 0.61 | 150 | 19.4 | 1.5 |
| 1.22 | 240 | 18.5 | 2 |
| 1.83 | 260 | 18.3 | 2.4 |
| 2.44 | 320 | 18.2 | 2.4 |
| 3.05 | 320 | 18.1 | 2.5 |
| 3.66 | 340 | 18.1 | 2.6 |
| 4.27 | 420 | 17.6 | 2.9 |
| 4.88 | 480 | 16.8 | 3.8 |
| 5.49 | 500 | 16.3 | 3.8 |
| 6.10 | 500 | 16.2 | 3.9 |
| 6.71 | 360 | 14.8 | 4.5 |
| 7.32 | 540 | 11.3 | 6.7 |
| 7.93 | 580 | 11 | 6.7 |
| 8.54 | 500 | 10 | 7.3 |
| 9.76 | 580 | 8.1 | 8.4 |
| 10.37 | 400 | 3.9 | 10 |
| 10.98 | 220 | 2.3 | 10.4 |
| 11.59 | 300 ^b | 2.6 | 10.4 |

^aBy volume.

^bDilution bag used.

Figure 5.15 summarizes the calibration, which has a zero mean and an error standard deviation of 50%.

5.3.2 Ambient Assimilative Capacity for Total Hydrocarbon Vapors

The ambient calibrated parameter values support an estimate of the assimilative capacity of the subsurface to degrade JP4 jet fuel vapors in the study area. The flux of oxygen entering the ground (J_{XO} , Equation 5.31b) is assumed to be consumed by aerobic degradation in the subsurface, a process that generates a stoichiometrically proportional flux of carbon dioxide entering the atmosphere. It is instructive to compare J_{XO} to the flux of total hydrocarbon vapors leaving the capillary fringe J_{GF}

$$J_{GF} = -\theta D_{GS} \frac{dG_S}{dz} \quad (z=-b_F) \quad (5.36a)$$

$$J_{GF} = \theta G_O \sqrt{\lambda_G D_{GS}} \tanh(z_O \sqrt{\frac{\lambda_G}{D_{GS}}}) \quad (\text{ambient}) \quad (5.36b)$$

TABLE 5.32 SOIL GAS CONSTITUENTS IN VAPOR PROBE VP2

| Depth, m | p _G , ppm | p _X , % ^a | p _C , % |
|----------|----------------------|---------------------------------|--------------------|
| 0 | NS ^b | 20.9 | NS |
| 0.61 | NS | 19.6 | NS |
| 1.22 | NS | 18.9 | NS |
| 1.83 | NS | 19 | NS |
| 2.44 | NS | 19.5 | NS |
| 3.05 | NS | 19.4 | NS |
| 3.66 | NS | 18 | NS |
| 4.27 | NS | 16.5 | NS |
| 4.88 | NS | 15.3 | NS |
| 5.49 | NS | 15.4 | NS |
| 6.10 | NS | 15.4 | NS |
| 6.71 | NS | 18 | NS |
| 7.32 | NS | 16.8 | NS |
| 7.93 | NS | 10.7 | NS |

^aDownhole oxygen probe, % by volume.^bNot sampled.**TABLE 5.33 SOIL GAS CONSTITUENTS IN VAPOR PROBE VP3**

| Depth, m | p _G , ppm ^a | p _X , % ^a | p _C , % ^a |
|----------|-----------------------------------|---------------------------------|---------------------------------|
| 0.30 | 0 | 20.7 | 0.8 |
| 0.61 | 0 | 19.9 | 1.4 |
| 0.91 | 10 | 19.6 | 1.7 |
| 1.22 | 60 | 19.4 | 1.9 |
| 1.52 | 40 | 19.2 | 2 |
| 1.83 | 20 | 19.2 | 2.1 |
| 2.13 | 60 | 19.1 | 2.2 |
| 2.44 | 60 | 19.4 | 2.3 |
| 2.74 | 50 | 18.9 | 2.3 |
| 3.05 | 60 | 18.7 | 2.4 |
| 3.35 | 60 | 18.4 | 2.6 |
| 3.66 | 80 | 18 | 3 |
| 3.96 | 100 | 17.8 | 3.2 |
| 4.27 | 110 | 17.8 | 3.2 |
| 4.57 | 120 | 17.7 | 3.3 |
| 4.88 | 100 | 17.7 | 3.3 |
| 5.18 | 120 | 13.3 | 5.9 |
| 5.49 | 120 | 12.1 | 6.6 |
| 5.79 | 130 | 11.6 | 6.8 |
| 6.10 | 140 | 11.4 | 6.8 |

^aBy volume.

TABLE 5.34 SOIL GAS CONSTITUENTS IN VAPOR PROBE 12BC

| Depth, m | p _G , ppm ^a | p _X , % ^a | p _C , % ^a | p _Y , ppm ^a |
|----------|-----------------------------------|---------------------------------|---------------------------------|-----------------------------------|
| 10.06 | 0 | 21.7 | 1.5 | 49 |
| 10.37 | 260 | 18.7 | 1.2 | 107 |
| 10.52 | 280 | 18.8 | 1.1 | 118 |
| 10.67 | 340 | 18.7 | 1.2 | 144 |
| 10.82 | 450 | 18.6 | 1.1 | 181 |
| 10.98 | 620 | 18.6 | 1.2 | 226 |
| 10.98 | 740 | 18.6 | 1.2 | 273 |
| 11.12 | 800 | 18.5 | 1.2 | 299 |
| 11.28 | 820 | 21.6 | 0.0 | 80 |

^aBy volume.

^bNot sampled.

TABLE 5.35 SOIL GAS CONSTITUENTS IN VAPOR PROBE 12BE

| Depth, m | p _G , ppm ^a | p _X , % ^a | p _C , % ^a | p _Y , ppm ^a |
|----------|-----------------------------------|---------------------------------|---------------------------------|-----------------------------------|
| 9.5 | 200 | 18.0 | 0.66 | 54 |
| 9.6 | 200 | 18.0 | 0.72 | 48 |
| 9.8 | 220 | 18.0 | 0.72 | 48 |
| 9.9 | 320 | 18.0 | 0.6 | 52 |
| 10.1 | 320 | 18.0 | 0.57 | 49 |
| 10.2 | 300 | 18.0 | 0.58 | 49 |
| 10.4 | 300 | 18.0 | 0.52 | 34 |
| 10.7 | 280 | 18.1 | 0.65 | 54 |
| 10.8 | 300 | 18.1 | 0.66 | 52 |
| 11.0 | 300 | 18.1 | 0.67 | 50 |
| 11.1 | 280 | 18.1 | 0.67 | 50 |
| 11.3 | 280 | 18.1 | 0.67 | 46 |
| 11.4 | 300 | 18.0 | 0.62 | 56 |

^aBy volume.

^bNot sampled.

We derive Equation 5.34b from the steady profile of Equation 4.26. We evaluate D_{GS} using Equations 4.28b and 4.29, adopt an ambient G_F value of 0.001 kg/m^3 , set b_F equal to 13 m, and compute the steady, ambient hydrocarbon diffusion rate entering the unsaturated zone as

$$J_{GF} = 8.92 \times 10^{-11} \frac{\text{kg}}{\text{m}^2 - \text{s}} \quad (\text{ambient diffusion}) \quad (5.37a)$$

$$D_{GS} = 4.37 \times 10^{-6} \frac{\text{m}^2}{\text{s}} \quad (5.37b)$$

TABLE 5.36 SOIL GAS CONSTITUENTS IN VAPOR PROBE 12BH

| Depth, m | p_G , ppm ^a | p_X , % ^a | p_C , % ^a | p_Y , ppm ^a |
|----------|--------------------------|------------------------|------------------------|--------------------------|
| 9.3 | 110 | 20.0 | 0.310 | 81 |
| 9.5 | 140 | 20.0 | 0.064 | 85 |
| 9.6 | 200 | 19.8 | 0.18 | 121 |
| 9.8 | 220 | 19.9 | 0.18 | 123 |
| 9.9 | 220 | 19.9 | 0.18 | 121 |
| 10.1 | 230 | 19.8 | 0.183 | 122 |
| 10.2 | 230 | 19.9 | 0.184 | 128 |
| 10.4 | 220 | 19.8 | 0.184 | 121 |
| 10.5 | 210 | 19.9 | 0.186 | 92 |
| 10.7 | 210 | 19.8 | 0.190 | 130 |
| 10.8 | 200 | 19.9 | 0.167 | 119 |
| 11.0 | 210 | 19.9 | 0.171 | 118 |

^aBy volume.

TABLE 5.37 SOIL GAS CONSTITUENTS IN VAPOR PROBE 12BJ

| Depth, m | p_G , ppm ^a | p_X , % ^a | p_C , % ^a | p_Y , ppm ^a |
|----------|--------------------------|------------------------|------------------------|--------------------------|
| 9.3 | 160 | 19.5 | 0.222 | 140 |
| 9.8 | 150 | 19.6 | 0.234 | 141 |
| 9.9 | 140 | 19.5 | 0.262 | 139 |
| 10.1 | 140 | 19.6 | 0.267 | 145 |
| 10.2 | 140 | 19.4 | 0.290 | 144 |
| 10.4 | 140 | 19.6 | 0.287 | 146 |
| 10.5 | 140 | 19.5 | 0.292 | 147 |
| 10.7 | 120 | 19.9 | 0.471 | 132 |
| 10.8 | 120 | 20.1 | 0.491 | 129 |
| 11.0 | 100 | 20.1 | 1.00 | 38 |

^aBy volume.

We compare Eqs. 5.31b and 5.37a and conclude that the hydrocarbon vapor flux leaving the capillary fringe is far less than the oxygen and carbon dioxide fluxes entering the soil

$$J_{XO} \gg J_{GF} \quad (\text{ambient diffusion}) \quad (5.38)$$

The aerobic degradation responsible for oxygen consumption and carbon dioxide generation, must occur in the capillary fringe, reducing hydrocarbon vapor concentrations from values near saturation to the low levels found in the unsaturated zone.

We compute the natural attenuation rate λ_F in the capillary fringe by equating the oxygen supply rate to the product of the air volume in the fringe and the attenuation rate, adjusted for stoichiometry

TABLE 5.38 SOIL GAS CONSTITUENTS IN VAPOR PROBE 12BK

| Depth, m | p _G , ppm ^a | p _X , % ^a | p _C , % ^a | p _Y , ppm ^a |
|----------|-----------------------------------|---------------------------------|---------------------------------|-----------------------------------|
| 9.30 | 100 | 13.2 | 3.3 | 35 |
| 9.45 | 100 | 13.5 | 3.6 | 31 |
| 9.60 | 100 | 13.3 | 3.6 | 33 |
| 9.76 | 100 | 13.3 | 3.6 | 33 |
| 9.91 | 100 | 13.4 | 3.1 | 29 |
| 10.06 | 110 | 14.1 | 2.3 | 18 |
| 10.21 | 240 | 17.0 | 1.4 | 78 |
| 10.37 | 300 | 16.8 | 1.2 | 82 |
| 10.52 | 340 | 16.6 | 1.3 | 85 |
| 10.67 | 420 | 16.5 | 1.3 | 84 |
| 10.82 | 460 | 16.9 | 1.3 | 83 |
| 10.98 | 540 | 16.9 | 1.3 | 85 |
| 11.13 | 700 | 16.9 | 1.3 | 88 |

^aBy volume.

TABLE 5.39 SOIL GAS CONSTITUENTS IN VAPOR PROBE 12BM

| Depth, m | p _G , ppm ^a | p _X , % ^a | p _C , % ^a | p _Y , ppm ^a |
|----------|-----------------------------------|---------------------------------|---------------------------------|-----------------------------------|
| 9.30 | 120 | 16.0 | 1.5 | 48 |
| 9.45 | 110 | 16.2 | 1.5 | 53 |
| 9.60 | 110 | 15.7 | 1.5 | 50 |
| 9.76 | 110 | 16.8 | 1.3 | 47 |
| 9.91 | 110 | 16.7 | 1.3 | 45 |
| 10.06 | 180 | 17.5 | 1.1 | 84 |
| 10.21 | 180 | 17.2 | 1.0 | 90 |
| 10.37 | 190 | 17.3 | 1.1 | 96 |
| 10.52 | 200 | 17.1 | 1.1 | 107 |
| 10.67 | 230 | 17.2 | 1.1 | NS ^b |
| 10.82 | 240 | 17.1 | 1.1 | 157 |
| 10.98 | 280 | 17.1 | 1.1 | 190 |
| 11.13 | 340 | 16.9 | 1.2 | 202 |

^aBy volume.

$$J_{XO} \approx \lambda_F \zeta \theta G_{SAT} \gamma_X \quad (5.39a)$$

$$\lambda_F \approx 1.42 \times 10^{-6} s^{-1} \quad (5.39b)$$

Equation 5.39b is predicated on a saturated hydrocarbon vapor pressure G_{SAT} of 0.05 kg/m³ (10,000 ppm), an upper bound on the headspace vapor concentrations found during core

TABLE 5.40 SOIL GAS CONSTITUENTS IN VAPOR PROBE 12BN

| Depth, m | p _G , ppm ^a | p _X , % ^a | p _C , % ^a | p _Y , ppm ^a |
|----------|-----------------------------------|---------------------------------|---------------------------------|-----------------------------------|
| 9.30 | 200 | 18.6 | 0.48 | 163 |
| 9.45 | 230 | 18.8 | 0.48 | 165 |
| 9.60 | 240 | 18.7 | 0.46 | 178 |
| 9.76 | 220 | 18.6 | 0.45 | NS |
| 9.76 | NS ^b | NS | NS | NS |
| 9.91 | 240 | 18.7 | 0.43 | 181 |
| 10.06 | 280 | 18.4 | 0.41 | 131 |
| 10.21 | 320 | 18.5 | 0.60 | 204 |
| 10.37 | 380 | 18.5 | 0.391 | 216 |
| 10.67 | 480 | 18.6 | 0.376 | 229 |
| 10.82 | 500 | 18.8 | 0.364 | 233 |
| 10.98 | 520 | 18.4 | 0.357 | 234 |

^aBy volume.

^bNot sampled.

sampling (Figure 3.5). The capillary fringe thickness ζ is assumed to be 1 m.

5.3.3 Helium Tracer Tests for Soil Venting and Air Sparging

We analyze the helium tracer data with the finite element model described in Section 4.4. A no (normal) flux boundary is imposed on the capillary fringe (as well as on the vertical axis), and zero concentrations are imposed at the ground surface and the radius of influence

$$H = 0 \quad (r=r_E) \quad (5.40a)$$

$$H = 0 \quad (z=0) \quad (5.40b)$$

$$\frac{\partial H}{\partial r} = 0 \quad (r=0, z > -b_F) \quad (5.40c)$$

$$\frac{\partial H}{\partial z} = 0 \quad (r > 0, z = -b_F) \quad (5.40d)$$

The model is run from a pure initial condition on the assumption of steady pneumatics.

We test the model by using measured or estimated parameter values for all input data. The volumetric discharge is set at its measured value cited in Equation 3.8, while the total and air porosities are given by independently observed data summarized in Equations 5.11b and 5.13. Soil temperature is specified by Equations 5.1 and 5.3, while the hydrocarbon diffusivity is

computed in accordance with Equation 4.33, yielding the steady helium diffusivity cited in Table 4.2. The radial coordinates r_p of the cluster points are computed from their surveyed positions (Table 3.1), using the injection point coordinates x_{INJ} , y_{INJ} (in feet) as the origin

$$r_p = \sqrt{\frac{(x_p - x_{INJ})^2 + (y_p - y_{INJ})^2}{10.76}} \quad (5.41)$$

The sparge or venting injection point is set on the capillary fringe, and the radius of influence is set at 15 m for both tests

$$r_E = 15\text{m} \quad (5.42a)$$

$$b_F = 13\text{m} \quad (\text{venting and sparging}) \quad (5.42b)$$

We assess the accuracy of the model tests using statistics of the helium error δ_H defined by

$$\delta_H = H_{\text{MEASURED}} - H_{\text{PREDICTED}} \quad (5.43a)$$

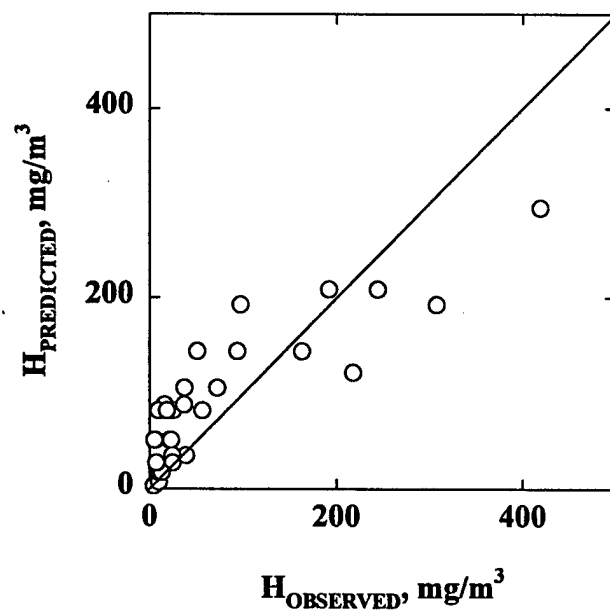
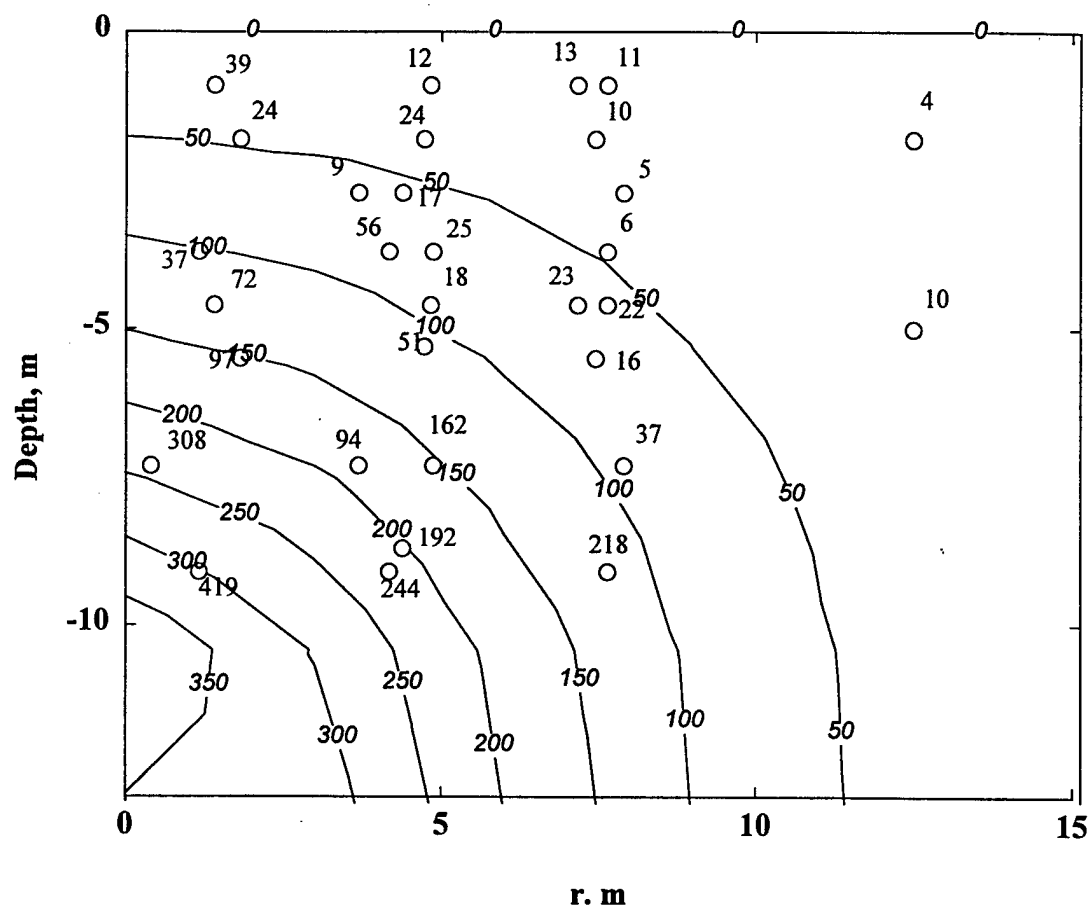
$$\delta_{HS} = \frac{1}{N} \sum \delta_H \quad (5.43b)$$

$$\sigma_H = \sqrt{\frac{1}{N} \delta_H^2 - \delta_{HM}^2} \quad (5.43c)$$

We predict the helium concentration H_p at an arbitrary point by interpolating adjacent nodal values H_i . Round 2 sampling data are used in both venting and sparging tests, to minimize effects of transient pneumatics on the theory.

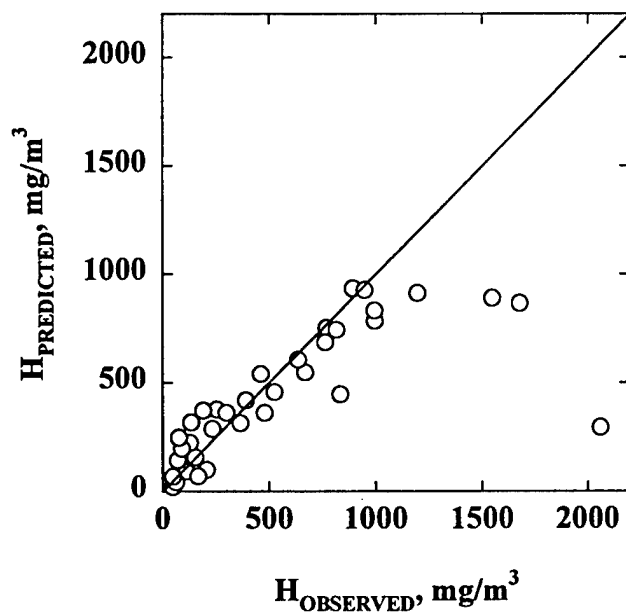
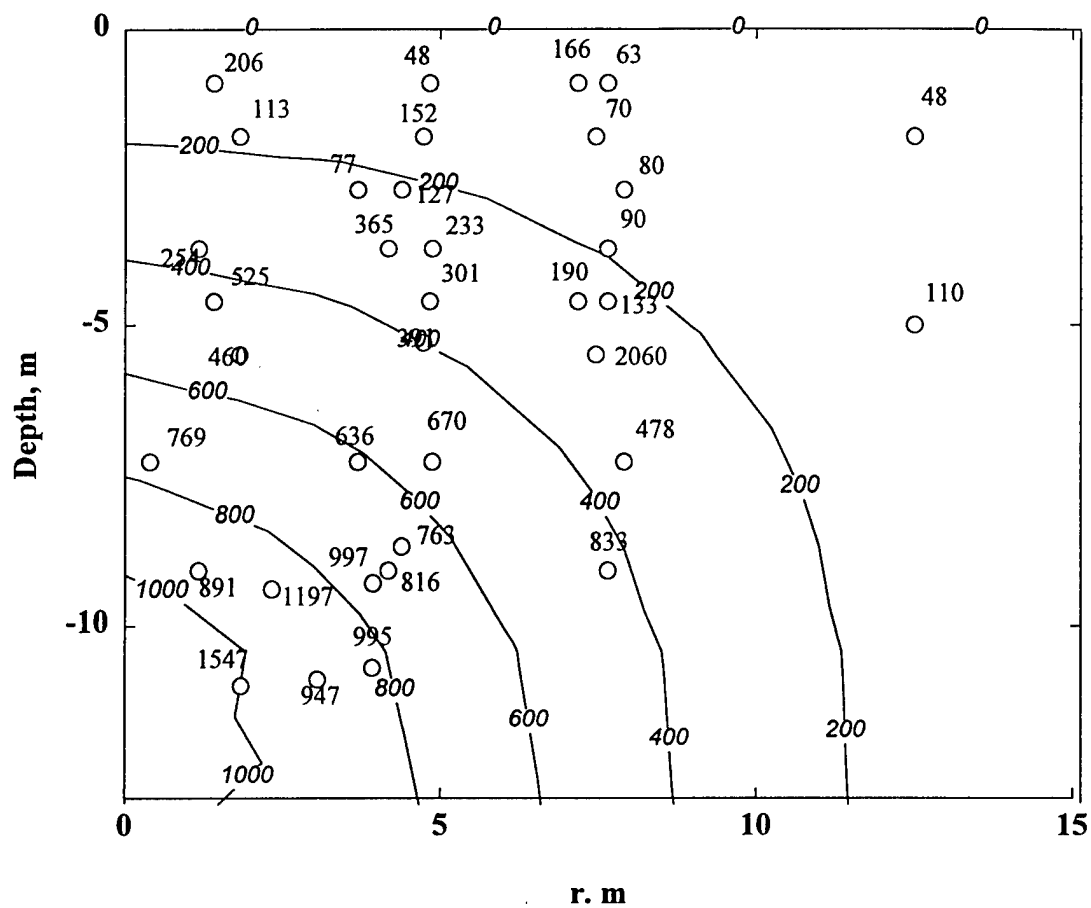
Figure 5.16 summarizes Round 2 testing for soil venting. We note a mean helium model error δ_{HS} of 18 mg/m^3 , and an error standard deviation σ_H of 53 mg/m^3 , which are an order of magnitude less than the injection concentration H_{INJ} of 347 mg/m^3 cited in Table 3.6. The data are predictions are plotted as a contour diagram, and a scatter plot on the figure--we tend to overpredict smaller, more distant, concentrations and underpredict larger concentrations near the origin. The former error may reflect transient pneumatics near the leading edge of the injection, while the latter error may be attributed in part to schematizing the venting injection as a single point. The test results are encouraging nonetheless, particularly in view of the scatter inherent in field sampling under the adverse weather conditions of upstate New York.

Figure 5.17 summarizes Round 2 testing for air sparging, based on an injection concentration of $1,010 \text{ mg/m}^3$ (Table 3.6). The mean model error of 105 mg/m^3 and the error standard deviation of 341 mg/m^3 are also an order of magnitude less than the injection concentration. As with the soil venting test, the strong concentrations are slightly overpredicted, while the distant, weaker data are somewhat underpredicted. Taken together, the consistent test



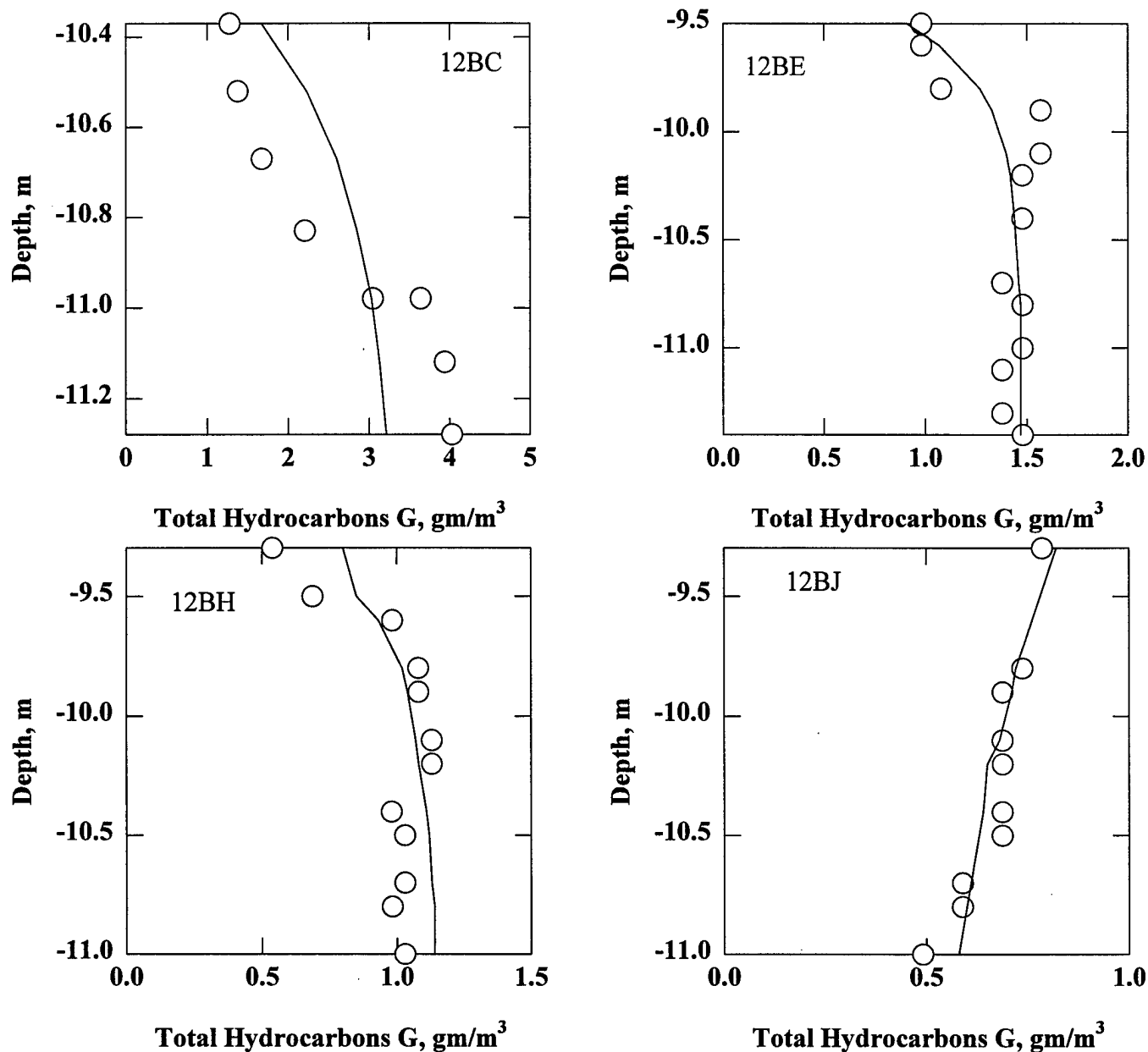
Note: Straight line is perfect model prediction.

Figure 5.16 Observed and Predicted Helium Concentrations for Soil Venting (Round 2)



Note: Straight line is perfect model prediction.

Figure 5.17 Observed and Predicted Helium Concentrations for Air Sparging (Round 2)



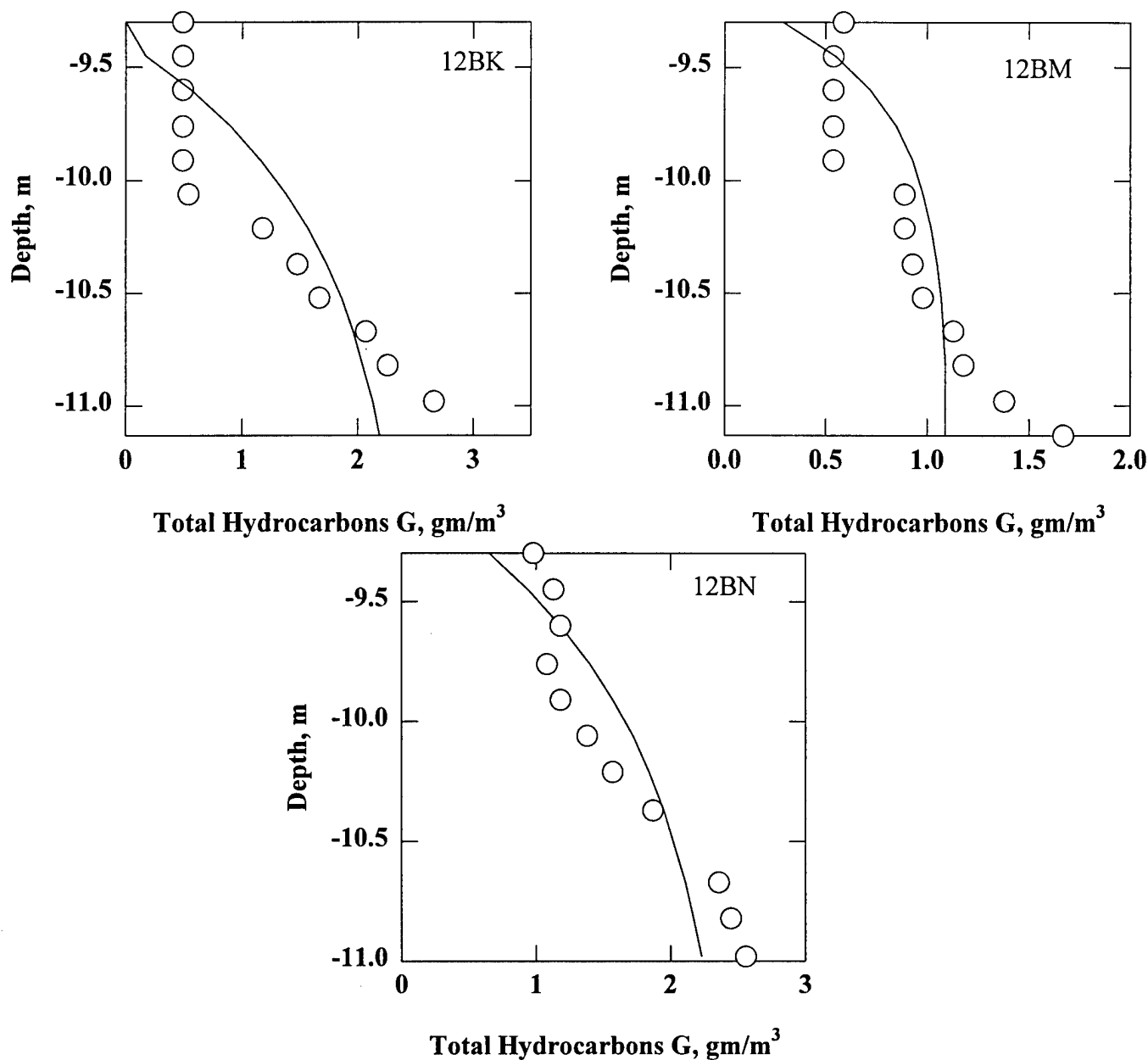
Note: Data Observed on 22 August 1996, after 12 days of air sparging

Figure 5.18 Observed (Symbols) and Calibrated (Curves) Total Hydrocarbon Concentrations in Vapor Probe Boreholes

accuracy endorses the physical validity of the model approach, the adequacy of field sampling methodology, and confirms the values of the advective and diffusive transport coefficients.

5.3.4 Soil Venting and Air Sparging of Total Hydrocarbons

We documented the initial response of the study area to air sparging (9 August 1995 startup) with a round of stainless steel tubing cluster sampling (20 August 1996, Table 5.25) and



Note: Data Observed on 22 August 1996, after 12 days of air sparging

Figure 5.18 (Continued) Observed (Symbols) and Calibrated (Curves) Total Hydrocarbon Concentrations in Vapor Probe Boreholes

vapor probes (boreholes 12BC, 12BE, 12BH, 12BJ, 12BK, 12BM, and 12BN, Tables 5.34-5.40).

The vapor probes delineate the vertical profile near the capillary fringe in an attempt to quantify boundary conditions for the finite element grid. We calibrate the quasi steady vertical profile model for total hydrocarbons (Equation 4.59) with the results summarized in Figure 5.18 and Table 5.41. The fringe concentration G_F zeroed the mean hydrocarbon error δ_{GM} , while the

**TABLE 5.41 TOTAL HYDROCARBON PROFILE CALIBRATION NEAR
CAPILLARY FRINGE**

| Borehole | σ_G , gm/m ³ | G_F , gm/m ³ | J_{GF} , $\mu\text{g}/\text{m}^2\text{-s}$ | r, m | w_F , m/s |
|----------|--------------------------------|---------------------------|--|------|-----------------------|
| 12BC | 0.68 | 3.36 | 11.4 | 2.83 | 3.38×10^{-6} |
| 12BE | 0.12 | 1.45 | 6.26 | 1.91 | 4.29×10^{-6} |
| 12BH | 0.11 | 1.18 | 2.04 | 4.19 | 1.73×10^{-6} |
| 12BJ | 0.04 | 0.465 | 0.26 | 7.22 | 6.51×10^{-7} |
| 12BK | 0.56 | 2.45 | 3.79 | 4.53 | 1.53×10^{-6} |
| 12BM | 0.25 | 1.10 | 3.46 | 2.62 | 3.13×10^{-6} |
| 12BN | 0.28 | 2.48 | 3.55 | 4.75 | 1.42×10^{-6} |

fringe flux J_{GF} minimizes the error standard deviation σ_G , with the error δ_G and statistics defined by Equation 5.32. The error standard deviation ranges from 0.04 to 0.68 gm/m³, while the calibrated fringe concentration is between 0.47 and 3.36 gm/m³ in magnitude. The average of the seven fringe concentrations and fringe hydrocarbon fluxes induced by air sparging is given by

$$G_F = 1.78 \frac{\text{mg}}{\text{m}^3} \quad (\text{air sparging, vapor probes}) \quad (5.44a)$$

$$J_{GF} = 4.39 \frac{\mu\text{g}}{\text{m}^2 \cdot \text{s}} \quad (\text{air sparging, vapor probes}) \quad (5.44b)$$

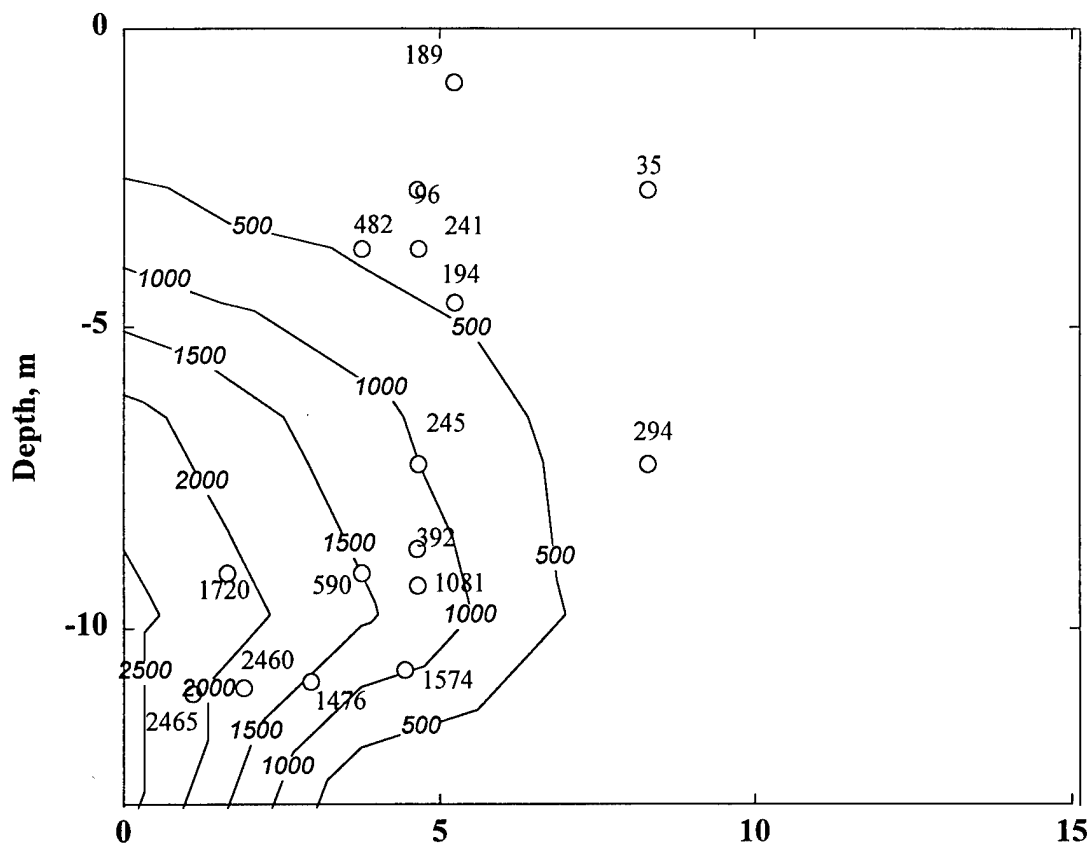
We note that sparging stimulates an initial hydrocarbon evaporation rate two orders of magnitude higher than ambient diffusion (Equation 5.37a).

The 20 August 1996 tubing cluster data are distributed over the entire study area, and are accordingly amenable to analysis by the finite element code. We impose a zero boundary condition on the capillary fringe in place of Equation 5.40d, input the reference diffusivity for total hydrocarbons (Table 4.2), and optimize the hydrocarbon model error with the injection concentration G_{INF} . Figure 5.19 displays the results of the calibration, based on the following parameter values

$$G_{INF} = 2.66 \frac{\text{gm}}{\text{m}^3} \quad (\text{air sparging, tubing cluster}) \quad (5.45a)$$

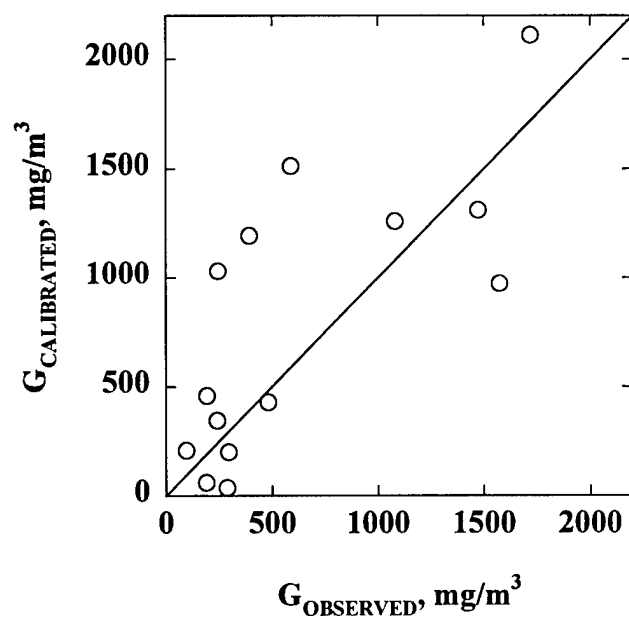
$$\delta_{GM} = 0.06 \frac{\text{gm}}{\text{m}^3} \quad (5.45b)$$

$$\sigma_G = 0.6 \frac{\text{gm}}{\text{m}^3} \quad (5.45c)$$



Note: Data from 20 August 1996

r. m



Note: Straight line is perfect model prediction, tubing cluster data.

Figure 5.19 Observed and Calibrated Hydrocarbon Concentrations for Air Sparging

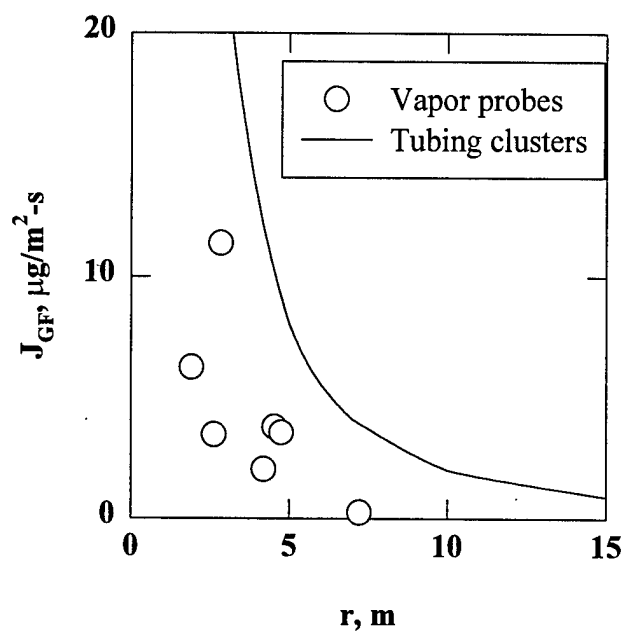


Figure 5.20 Vertical Hydrocarbon Flux Estimates by Vapor Probe Profiles (Symbols) and Stainless Steel Tubing Clusters (Curve)

We infer the sparged flux F_{GSPARGE} of total hydrocarbons by multiplying the calibrated injection concentration by the volumetric discharge with the result

$$F_{\text{GSPARGE}} = QG_{\text{INJ}} \quad (5.46a)$$

$$F_{\text{GSPARGE}} = 1.26 \times 10^{-6} \frac{\text{kg}}{\text{s}} \quad (5.46b)$$

This flux advects and diffuses radially (spherically) away from the sparge point. We derive a rough estimate of the vertical flux component near the capillary fringe by dividing the half of this flux by the projected area of the sphere on the horizontal plane with the result

$$J_{\text{GF}} \approx \frac{QG_{\text{INJ}}}{2\pi r^2} \quad (5.47)$$

We plot this radial variation on Figure 5.20, along with the calibrated values inferred from the vapor probe data. The decrease of flux with distance from the sparge point is apparent.

We monitored the soil venting of total hydrocarbon vapors with the stainless steel tubing clusters from startup of soil venting on 18 January 1996 to shutdown on 9 August 1996. Venting proceeded without interruption over this six month period, as documented by Tables 5.17-5.23. We fit the finite element model to the data by a Fibonacci search for G_{INJ} , with the results shown

**TABLE 5.42 SOIL VENTING OF TOTAL HYDROCARBONS
CALIBRATION RESULTS**

| Date | $\delta_{GM}, \text{gm/m}^3$ | $\sigma_G, \text{gm/m}^3$ | $G_{INF}, \text{gm/m}^3$ | Points | t, s^a |
|-----------|------------------------------|---------------------------|--------------------------|--------|--------------------|
| 7 Feb96 | 0.003 | 0.16 | 0.525 | 31 | 1.73×10^6 |
| 13 Feb96 | 0.011 | 0.13 | 0.363 | 31 | 2.25×10^6 |
| 7 Mar96 | 0.003 | 0.12 | 0.254 | 30 | 4.24×10^6 |
| 17 Mar96 | 0.003 | 0.15 | 0.404 | 31 | 5.10×10^6 |
| 4 Apr96 | 0.001 | 0.09 | 0.179 | 31 | 6.66×10^6 |
| 5 May96 | 0.013 | 0.12 | 0.401 | 31 | 9.34×10^6 |
| 15 Jun96 | 0.002 | 0.18 | 0.351 | 36 | 1.29×10^7 |
| 15 July96 | 0.010 | 0.12 | 0.179 | 37 | 1.55×10^7 |

^afrom start of soil venting.

in Table 5.42. The injection concentrations, which minimize the mean model error individual sampling trips, vary from 0.179 to 0.525 gm/m³, with an overall average of

$$G_{INJ} = 0.332 \frac{\text{gm}}{\text{m}^3} \quad (\text{soil venting}) \quad (5.48a)$$

$$F_{GVENT} = 1.56 \times 10^{-7} \frac{\text{kg}}{\text{s}} \quad (5.48b)$$

The error standard deviation ranges from 0.09 to 0.16 gm/m³ in magnitude. The spherical flux of total hydrocarbons entering the unsaturated zone F_{GVENT} is an order of magnitude less than that initially induced by air sparging. The efflux varies with time, although a systematic decrease is not evinced by the data. Figure 5.21 displays the observed and calibrated total hydrocarbon vapor concentrations on 7 February 1996, after 20 days of soil venting.

5.4 Trichloroethylene Vapor Concentrations

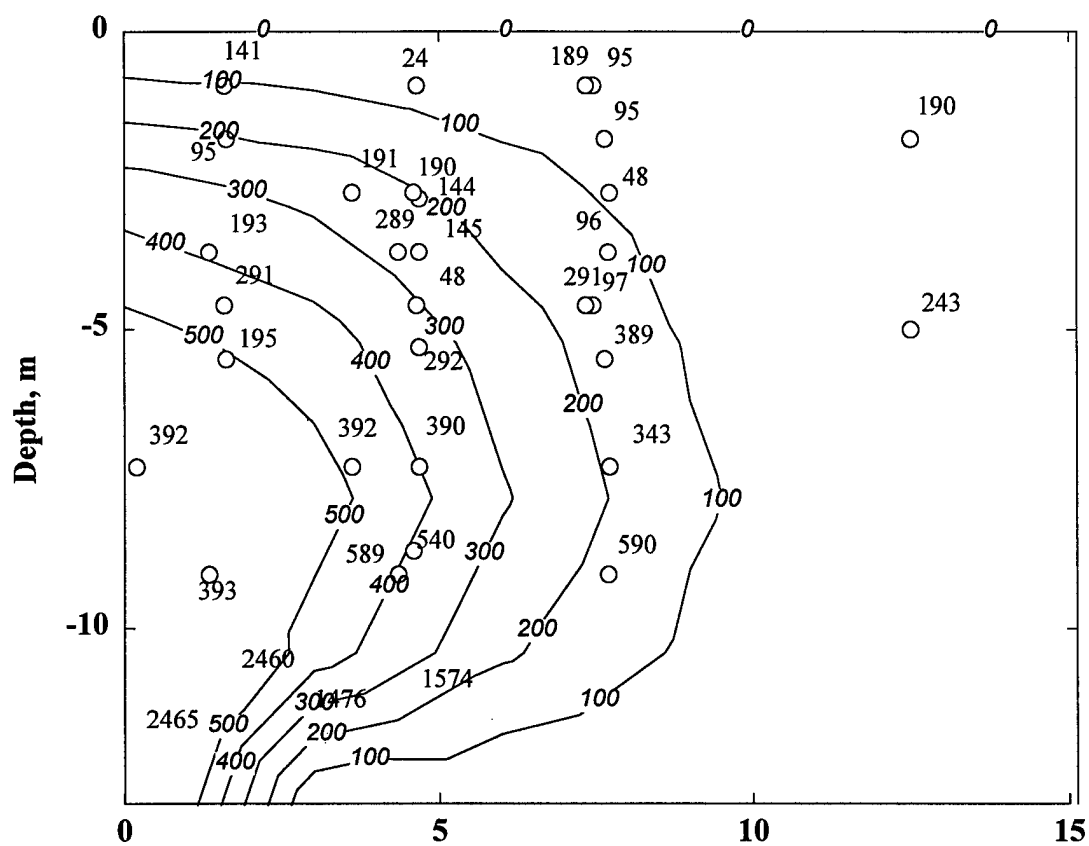
5.4.1 Trichloroethylene venting and sparging data

We analyze trichloroethylene soil gas concentrations in similar fashion to the total hydrocarbon data, based on the following parameter values:

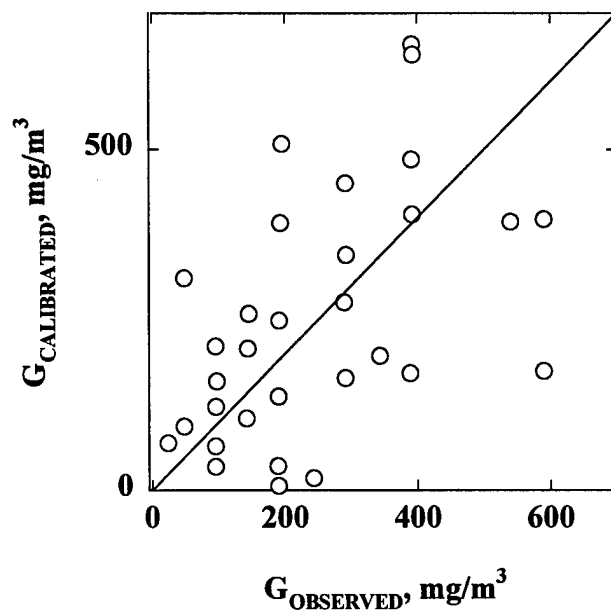
$$D_{YS} = 4.07 \times 10^{-6} \frac{\text{m}^2}{\text{s}} \quad (5.49a)$$

$$\lambda_{TCE} = 0 \quad (\text{unsaturated zone}) \quad (5.49b)$$

Soil venting is considered first. Tables 5.17-5.24 list the data, which are input to the finite element model. We calibrate values for the injection concentration Y_{INJ} by minimizing the TCE model error mean δ_{YM} , with the error δ_Y and error standard deviation σ_Y defined by



Note: Data from 7 February 1996



Note: Straight line is perfect model prediction, tubing cluster data.

Figure 5.21 Observed and Calibrated Hydrocarbon Concentrations for Soil Venting

**TABLE 5.43 SOIL VENTING OF TRICHLOROETHYLENE
CALIBRATION RESULTS**

| Date | δ_{YM} , gm/m ³ | σ_Y , gm/m ³ | Y_{INF} , gm/m ³ | Points | t, s ^a |
|----------|-----------------------------------|--------------------------------|-------------------------------|--------|----------------------|
| 7 Feb96 | 0.002 | 0.11 | 0.231 | 31 | 1.73x10 ⁶ |
| 13Feb96 | 0.037 | 0.07 | 0.181 | 31 | 2.25x10 ⁶ |
| 7 Mar96 | 0.001 | 0.09 | 0.125 | 30 | 4.24x10 ⁶ |
| 17Mar96 | 0.010 | 0.07 | 0.131 | 31 | 5.10x10 ⁶ |
| 4Apr96 | 0.022 | 0.06 | 0.125 | 31 | 6.66x10 ⁶ |
| 5May96 | 0.029 | 0.06 | 0.131 | 31 | 9.34x10 ⁶ |
| 15Jun96 | 0.022 | 0.05 | 0.119 | 31 | 1.29x10 ⁷ |
| 15July96 | 0.017 | 0.12 | 0.150 | 31 | 1.55x10 ⁷ |
| 9Aug96 | 0.005 | 0.13 | 0.150 | 31 | 1.77x10 ⁷ |

^afrom start of soil venting.

$$\delta_Y = Y_{MEASURED} - Y_{CALIBRATED} \quad (5.50a)$$

$$\delta_{YM} = \frac{1}{N} \sum \delta_Y \quad (5.50b)$$

$$\sigma_Y = \sqrt{\frac{1}{N} \delta_Y^2 - \delta_{YM}^2} \quad (5.50c)$$

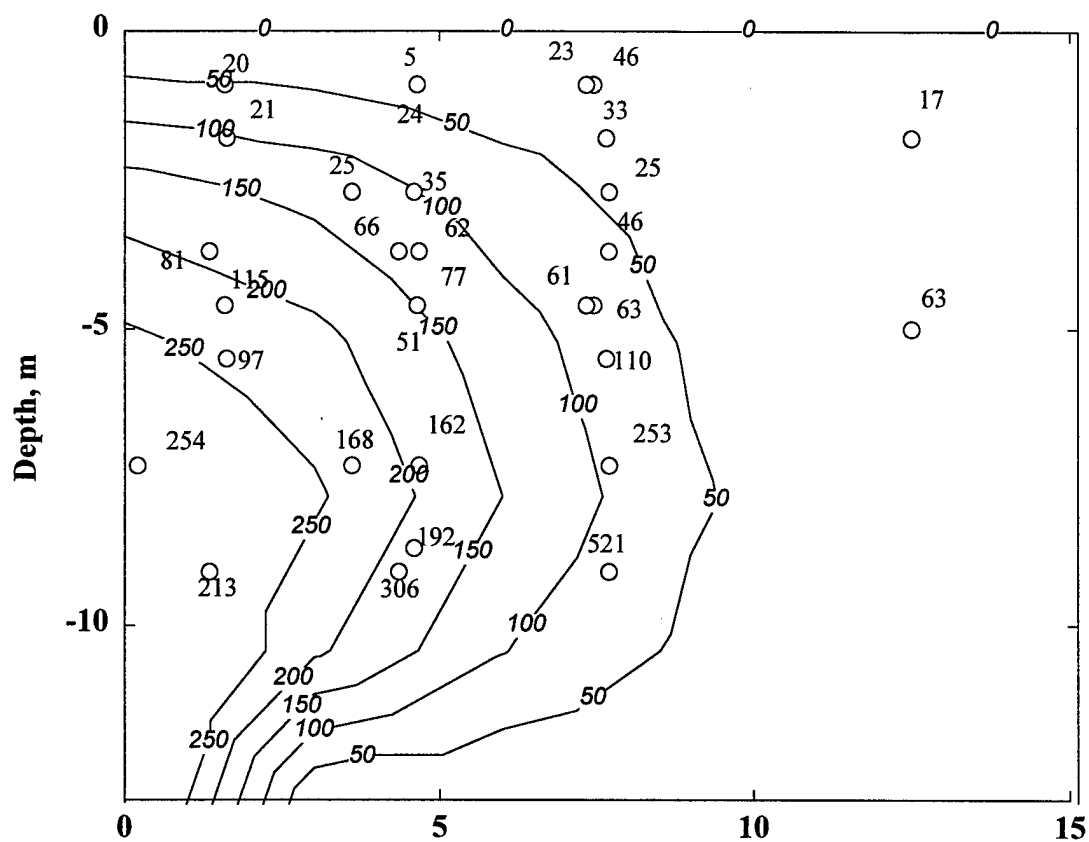
Table 5.43 summarizes the calibration results for trichloroethylene venting. Figure 5.22 displays typical TCE data and calibration for soil venting on 13 February 1996. The error standard deviation varies from 0.06 to 0.13 gm/m³, while the injection concentration ranges from 0.119 to 0.231 gm/m³ over seven months of venting. The average of the nine calibrations is

$$Y_{INJ} = 0.149 \frac{\text{gm}}{\text{m}^3} \quad (\text{soil venting}) \quad (5.51a)$$

$$\frac{Y_{INJ}}{Y_{SAT}} \approx 0.16 \quad (5.51b)$$

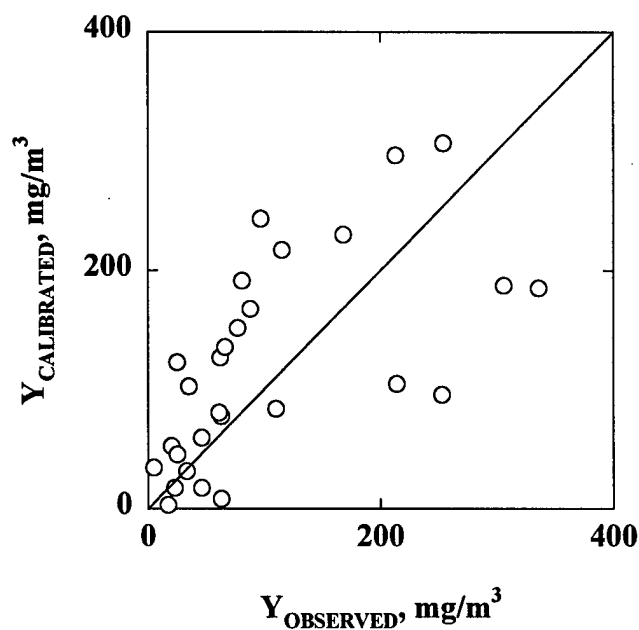
The calibrated injection concentration is one order of magnitude less than the (Equation 5.29a) value obtained by applying Raoult's law to the measured separate phase composition. This order of magnitude reduction is a typical gradient for the diffusive stripping of LNAPL vapors from separate phase contaminated soil by soil venting [Ostendorf et al. (1993b)]. This contrasts markedly with the corresponding ratio for total hydrocarbons implied by Equation 5.48 (with G_{SAT} estimated to be 0.05 kg/m³)

$$\frac{G_{INJ}}{G_{SAT}} \approx 0.007 \quad (\text{soil venting}) \quad (5.52)$$



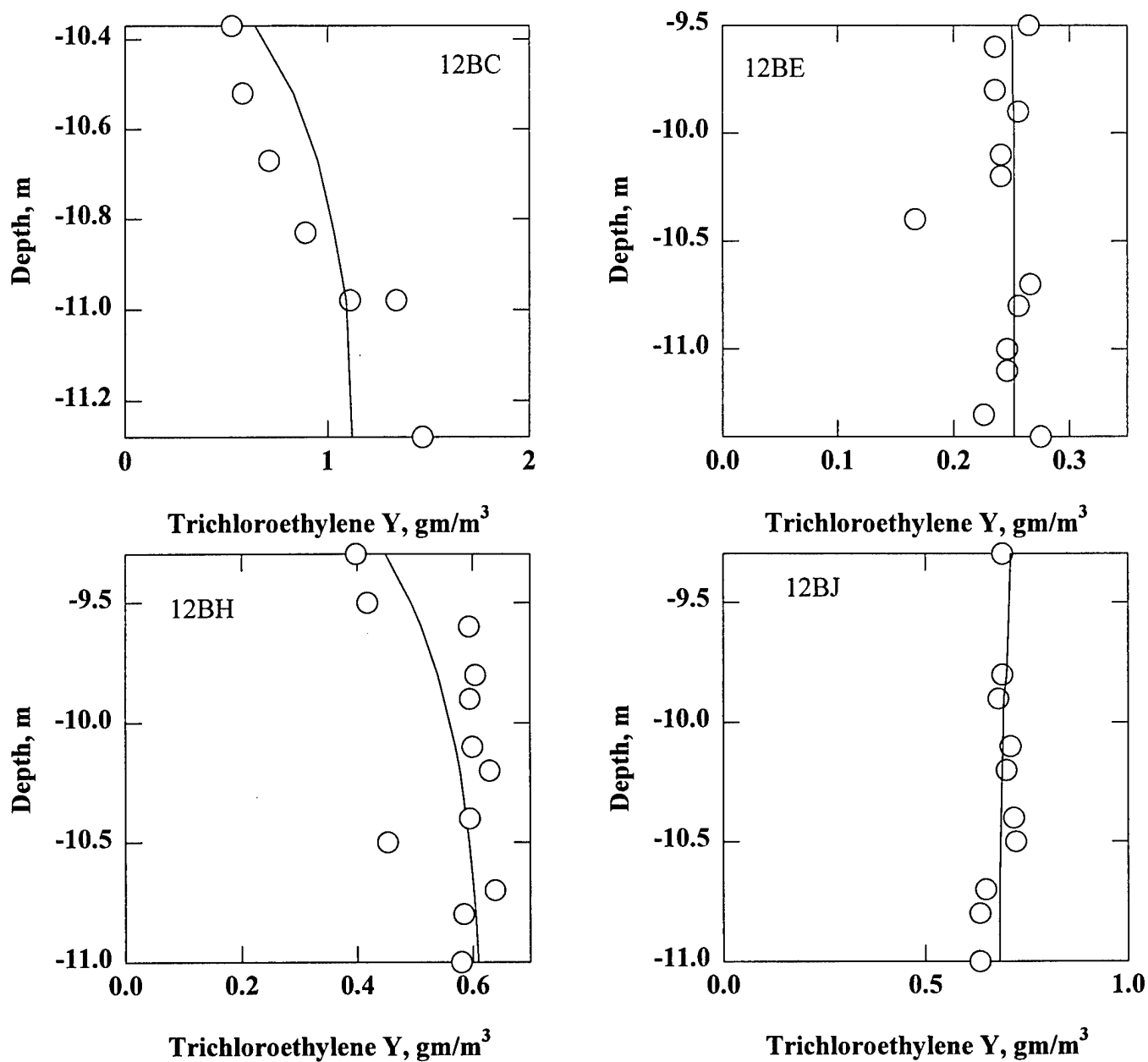
Note: Data from 7 February 1996

r. m



Note: Straight line is perfect model prediction, tubing cluster data.

Figure 5.22 Observed and Calibrated Trichloroethylene Concentrations for Soil Venting

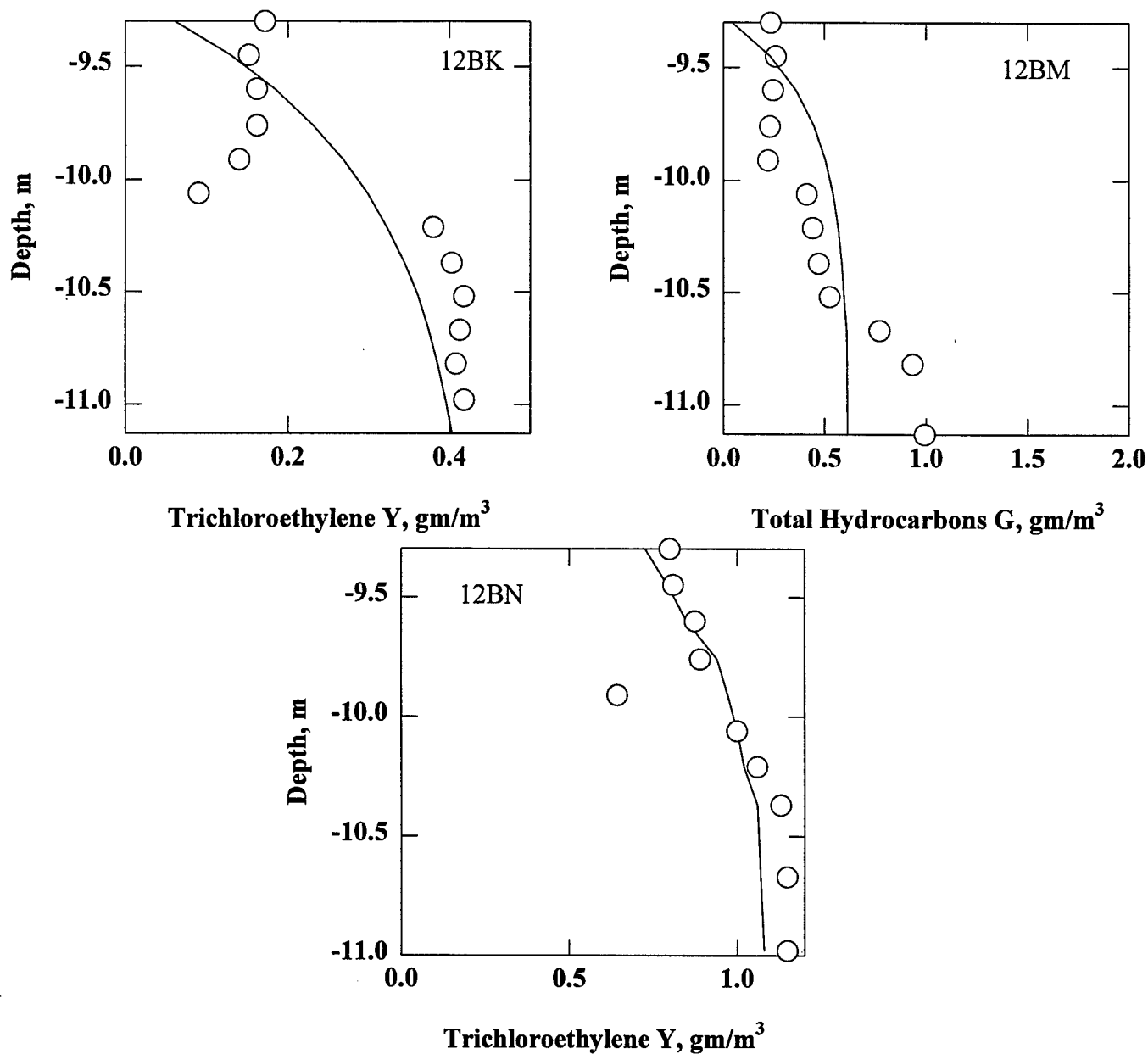


Note: Data observed on 22 August 1996, after 12 days of sparging

Figure 5.23 Observed (Symbols) and Calibrated (Curves) Trichloroethylene Concentrations in Vapor Probe Boreholes

We underscore the point by comparing the TCE to total hydrocarbon ratios for saturated conditions and for soil venting calibrations

$$\frac{Y_{\text{SAT}}}{G_{\text{SAT}}} \approx 0.019 \quad (\text{Raoult's law}) \quad (5.53a)$$



Note: Data observed on 22 August 1996, after 12 days of sparging

Figure 5.23 (Continued) Observed (Symbols) and Calibrated (Curves) Trichloroethylene Concentrations in Vapor Probe Boreholes

$$\frac{Y_{\text{INJ}}}{G_{\text{INJ}}} \approx 0.45 \quad (\text{soil venting}) \quad (5.53b)$$

Trichloroethylene accounts for nearly half of the vapors vented from the capillary fringe--a fraction 20 times greater than the ratio implied by Raoult's law.

**TABLE 5.44 TRICHLOROETHYLENE VAPOR PROFILE CALIBRATION
NEAR CAPILLARY FRINGE**

| Borehole | $\sigma_Y, \text{gm/m}^3$ | $Y_F, \text{gm/m}^3$ | $J_{YF}, \mu\text{g/m}^2\text{-s}$ | r, m | w_F, m/s |
|-----------------|---------------------------|----------------------|------------------------------------|-------------|---------------------------|
| 12BC | 0.21 | 1.18 | 4.00 | 2.83 | 3.38×10^{-6} |
| 12BE | 0.03 | 0.252 | 1.08 | 1.91 | 4.29×10^{-6} |
| 12BH | 0.06 | 0.623 | 1.08 | 4.19 | 1.73×10^{-6} |
| 12BJ | 0.03 | 0.669 | 0.43 | 7.22 | 6.51×10^{-7} |
| 12BK | 0.08 | 0.434 | 0.67 | 4.53 | 1.53×10^{-6} |
| 12BM | 0.21 | 0.618 | 1.94 | 2.62 | 3.13×10^{-6} |
| 12BN | 0.12 | 1.13 | 1.61 | 4.75 | 1.42×10^{-6} |

Table 5.44 and Figure 5.23 summarize the results of vapor probe trichloroethylene calibrations for air sparging on 22 August 1996. They are analogous to the total hydrocarbon vapor calibrations of Table 5.41 and Figure 5.18. The TCE concentration near the capillary fringe Y_F is chosen to zero the difference between the observed trichloroethylene and the constant flux layer prediction embodied by Equation 4.59. The error standard deviation varies between 0.03 and 0.21 gm/m³, while the fringe concentration implied by the vapor probe profiles ranges from 0.25 to 1.18 gm/m³, with an average value of

$$Y_F = 0.700 \frac{\text{gm}}{\text{m}^3} \quad (\text{air sparging, vapor probes}) \quad (5.54a)$$

$$\frac{Y_F}{G_F} \approx 0.39 \quad (\text{air sparging, vapor probes}) \quad (5.54b)$$

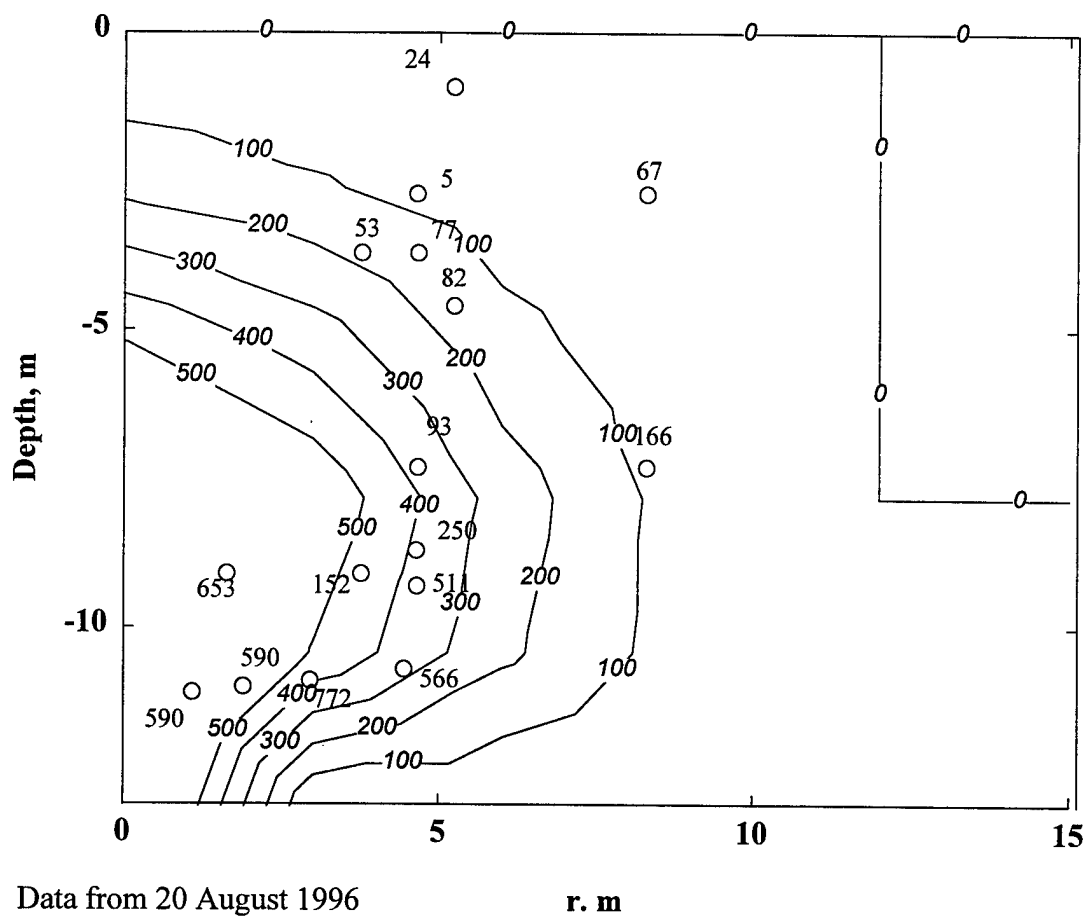
The ratio of the sparging induced trichloroethylene and total hydrocarbon (Equation 5.44a) concentrations near the fringe is quite similar to that exhibited by soil venting (Equation 5.53b). Total hydrocarbon vapors persist in the unsaturated zone, although trichloroethylene vapors do. In the latter regard, the average of the calibrated vertical TCE fluxes is

$$J_{YF} = 1.54 \frac{\mu\text{g}}{\text{m}^2\text{-s}} \quad (\text{air sparging, vapor probes}) \quad (5.55)$$

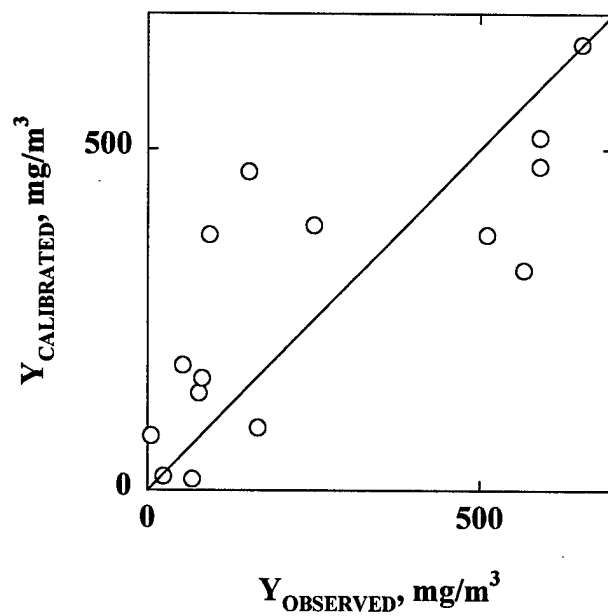
This is more than a third of the total hydrocarbon flux leaving the fringe (Equation 5.44b).

We calibrate the finite element model with the TCE sparging data of 22 August 1996 (Table 5.25). Figure 5.24 displays the results from a calibrated injection concentration of

$$Y_{\text{INJ}} = 0.550 \frac{\text{gm}}{\text{m}^3} \quad (\text{air sparging, tubing cluster}) \quad (5.56a)$$



Note: Data from 20 August 1996



Note: Straight line is perfect model prediction, tubing cluster data.

Figure 5.24 Observed and Calibrated Trichloroethylene Concentrations for Air Sparging

**TABLE 5.45 HELIUM AND TRICHLOROETHYLENE SOIL GAS
CONCENTRATIONS IN NAW 20 NOVEMBER 1996**

| Depth, m | p _Y , ppb ^a | p _H , ppm ^a | Depth, m | p _Y , ppb ^a | p _H , ppm ^a |
|--------------------|-----------------------------------|-----------------------------------|--------------------|-----------------------------------|-----------------------------------|
| 0.051 | 98 | 68 | 0.407 | 277 | 408 |
| 0.102 | 138 | 414 | 0.458 | 54 | 47 |
| 0.153 | 217 | 103 | 0.509 | 517 | 630 |
| 0.204 | 241 | 296 | 0.509 ^b | 666 | 500 |
| 0.254 | 234 | 384 | 0.636 | 605 | 481 |
| 0.254 ^b | 432 | 327 | 0.763 | 285 | 628 |
| 0.305 | 287 | 486 | 0.891 | 701 | 257 |
| 0.356 | 406 | 544 | 1.02 | 888 | 53 |

^aby volume.

^bcluster point.

$$\delta_{GM} = 0.001 \frac{\text{gm}}{\text{m}^3} \quad (5.56b)$$

$$\sigma_G = 0.17 \frac{\text{gm}}{\text{m}^3} \quad (5.56c)$$

$$\frac{Y_{\text{INJ}}}{G_{\text{INJ}}} \approx 0.21 \quad (5.56d)$$

The calibration standard deviation is 0.17 gm/m³, while the injection concentration is a significant fraction of the total hydrocarbon injection concentration (Equation 5.45a). The product of the volumetric discharge and the injection concentration is F_{YSPARGE} (Equation 5.46a), which for TCE is given by

$$F_{\text{YSPARGE}} = 2.60 \times 10^{-7} \frac{\text{kg}}{\text{s}} \quad (\text{air sparging, tubing cluster}) \quad (5.57)$$

5.4.2 Trichloroethylene degradation in the root zone

We also measured helium and trichloroethylene concentrations in the near surface array on 20 November 1996, during the course of the air sparging experiment. Tables 5.45 and 5.46 summarize the data. We analyze these vertically resolved profiles with the quasi steady, one dimensional advection, diffusion model of Section 4.5.1. Helium is considered first by ignoring reactions in Equation 4.57 with the result

**TABLE 5.46 HELIUM AND TRICHLOROETHYLENE SOIL GAS
CONCENTRATIONS IN NAE 20 NOVEMBER 1996**

| Depth, m | p _Y , ppb ^a | p _H , ppm ^a | Depth, m | p _Y , ppb ^a | p _H , ppm ^a |
|----------|-----------------------------------|-----------------------------------|----------|-----------------------------------|-----------------------------------|
| 0.051 | 51 | 31 | 0.407 | 379 | 219 |
| 0.102 | 140 | 36 | 0.458 | 360 | 171 |
| 0.153 | 141 | 39 | 0.509 | 288 | 214 |
| 0.204 | 150 | 109 | 0.636 | 463 | 51 |
| 0.254 | 259 | 62 | 0.763 | 540 | 132 |
| 0.305 | 243 | 138 | 0.891 | 734 | 259 |
| 0.356 | 291 | 139 | 1.02 | 745 | 231 |

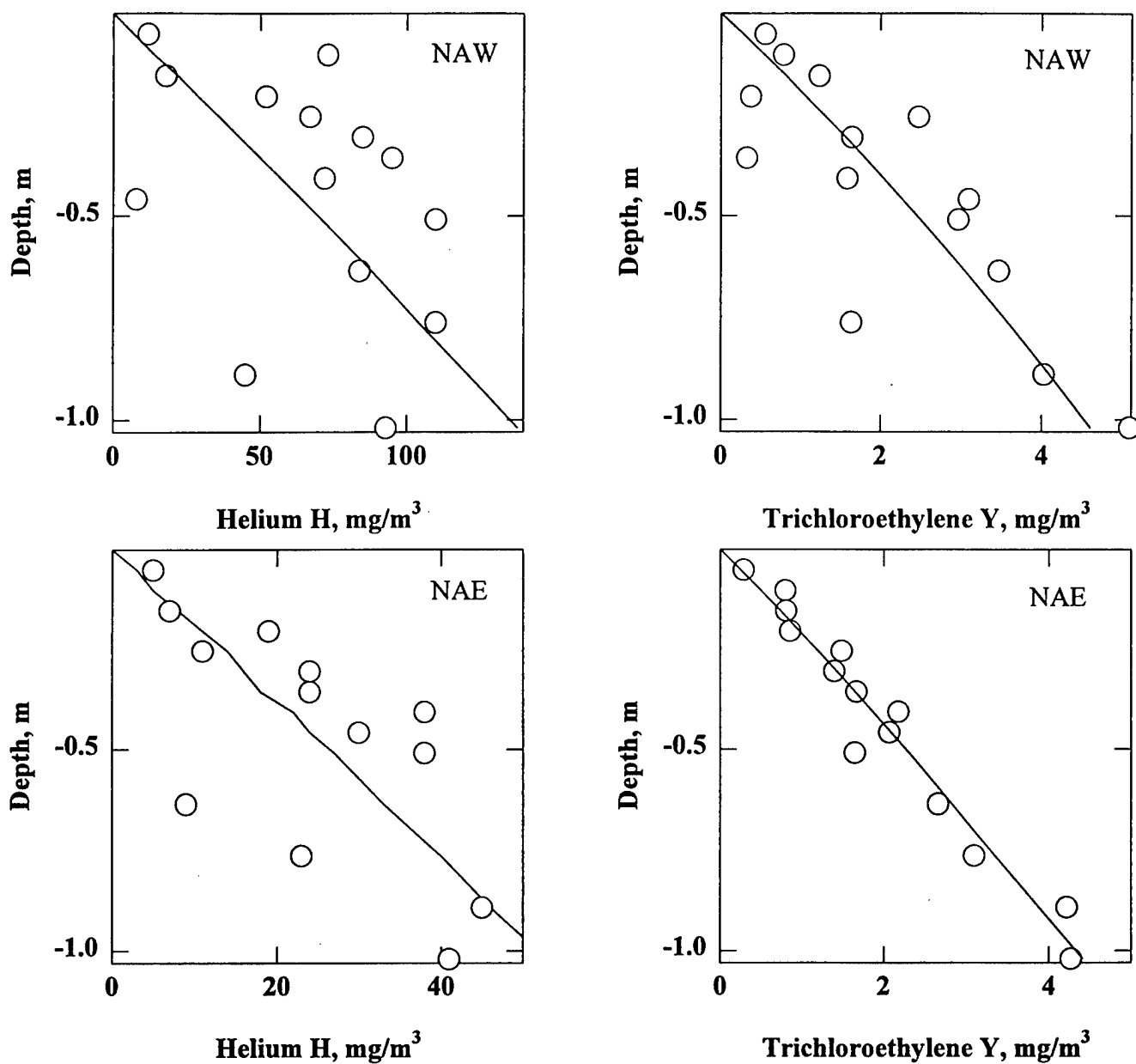
^aby volume.

$$H = H_0 \exp\left[\frac{w_0(z + b_R)}{2\theta D_H}\right] \left[\frac{\sinh\left(-\frac{w_0 z}{2\theta D_H}\right)}{\sinh\left(\frac{w_0 b_R}{2\theta D_H}\right)} \right] \quad (5.58)$$

We calibrate the theory with a ground surface temperature equal to 277.18°K, based on Equations 4.1c, 5.1, and 5.3b. The observed partial pressures are converted to concentrations with the ideal gas law (e.g. Equation 5.28), while the gaseous diffusivity is estimated at 2.25x10⁻⁵ m²/s. The latter value reflects Equations 4.33, 5.11b, and 5.13. The coordinates of Table 3.1 yield radial distances of 7.66 and 6.00 m, respectively, from the sparge point to NAE and NAW, so that the vertical specific discharges (Equation 4.19b) are 5.68x10⁻⁷ and 6.65x10⁻⁷ m/s.

Table 5.47 and Figure 5.25 summarize the near surface array calibrations. We use the helium data to calibrate the root zone thickness at each array through a nested Fibonacci search. The approach concentration (H₀) minimizes the mean helium model error, while b_R minimizes the error standard deviation. We find approach helium concentrations of 284 and 91 mg/m³ in NAW and NAE, which correspond to p_H values of 1,600 and 520 ppm, respectively. These values are consistent with the 20 November 1996 tubing cluster data cited in Table 5.30. The helium error standard deviations are 51 and 11 mg/m³ for the two arrays. The root zone thicknesses are then input to the trichloroethylene model (Equation 4.57), and we search for optimal Y₀ and degradation values. The TCE error standard deviations are 0.25 and 0.87 mg/m³ in NAW and NAE. The approach concentrations of 8.08 and 9.76 mg/m³ correspond to p_Y values (1.4 and 1.6 ppm) in keeping with the 21 November 1996 tubing cluster observations cited in Table 5.28. The near surface array data are consistent with the stainless steel tubing cluster data.

The calibrated TCE degradation rates are 2.26x10⁻⁶ s⁻¹ and 1.76x10⁻⁶ s⁻¹ at arrays NAW and NAE. The average of these two values is



Note: data from 20 November 1996, after 27 days of sparging and helium injection.

Figure 5.25 Observed (Symbols) and Calibrated (Curves) Helium and TCE Vapor Concentrations in Near Surface Arrays

$$\lambda_{\text{TCE}} = 2.01 \times 10^{-6} \text{ s}^{-1} \quad (\text{root zone}) \quad (5.59)$$

These kinetics are consistent with the results of Anderson and Walton (1995), who observe radiolabeled TCE degradation in the rhizosphere of aerobic soil plant microcosms. The

TABLE 5.47 NEAR SURFACE ARRAY CALIBRATION RESULTS

| | NAW | NAE |
|--------------------------------|-----------------------|-----------------------|
| $w_O, \text{m/s}$ | 6.65×10^{-7} | 5.68×10^{-7} |
| $H_O, \text{mg/m}^3$ | 284 | 91 |
| b_R, m | 2.24 | 1.83 |
| $\sigma_H, \text{mg/m}^3$ | 51 | 11 |
| $Y_O, \text{mg/m}^3$ | 8.08 | 9.76 |
| $\lambda_{TCE}, \text{s}^{-1}$ | 2.26×10^{-6} | 1.76×10^{-6} |
| $\sigma_Y, \text{mg/m}^3$ | 0.25 | 0.87 |

microcosms exhibit a TCE half life of about 5 days (corresponding to a first order decay coefficient of $1.6 \times 10^{-6} \text{ s}^{-1}$).

5.5 Total Hydrocarbon Assimilation Capacity Estimates and Surface Emissions

5.5.1 Oxygen and Carbon Dioxide Concentrations for Soil Venting

Figure 5.26 plots the temporal variation of the spatially averaged soil gas oxygen and carbon dioxide partial pressures with time from the onset of soil venting. These data are taken from Tables 5.16 to 5.23 excluding clusters 12AN, 12AT, and 12AX, which lie outside the study area. Soil vapor pressures from the control cluster are also shown in the figure, along with atmospheric values. We note that the control soil gas pressures are quite close to atmospheric levels, so it is apparent that soil venting depresses oxygen and elevates carbon dioxide in the unsaturated zone. We attribute this oxygen depletion and carbon dioxide elevation to aerobic degradation, and approximate the process by considering the difference between the average partial pressures in the study area (p_{XM}, p_{CM}) and control cluster ($p_{XCONTROL}, p_{CCONTROL}$)

$$\Delta X = \frac{1010(p_{XCONTROL} - p_{XM})m_X}{R_T \tau_\infty} \quad (p_{XM}=17.8\%) \quad (5.60a)$$

$$\Delta X = 0.0428 \frac{\text{kg}}{\text{m}^3} \quad (p_{XCONTROL}=20.9\%) \quad (5.60b)$$

$$\Delta C = \frac{1010(p_{CCONTROL} - p_{CM})m_C}{R_T \tau_\infty} \quad (p_{CM}=2.51\%) \quad (5.60c)$$

$$\Delta C = 0.0457 \frac{\text{kg}}{\text{m}^3} \quad (p_{CCONTROL}=0.1\%) \quad (5.60d)$$

Equation 4.22 details the stoichiometry assumed for complete mineralization of hydrocarbons by aerobic degradation. We accordingly convert the oxygen depletion ΔX and

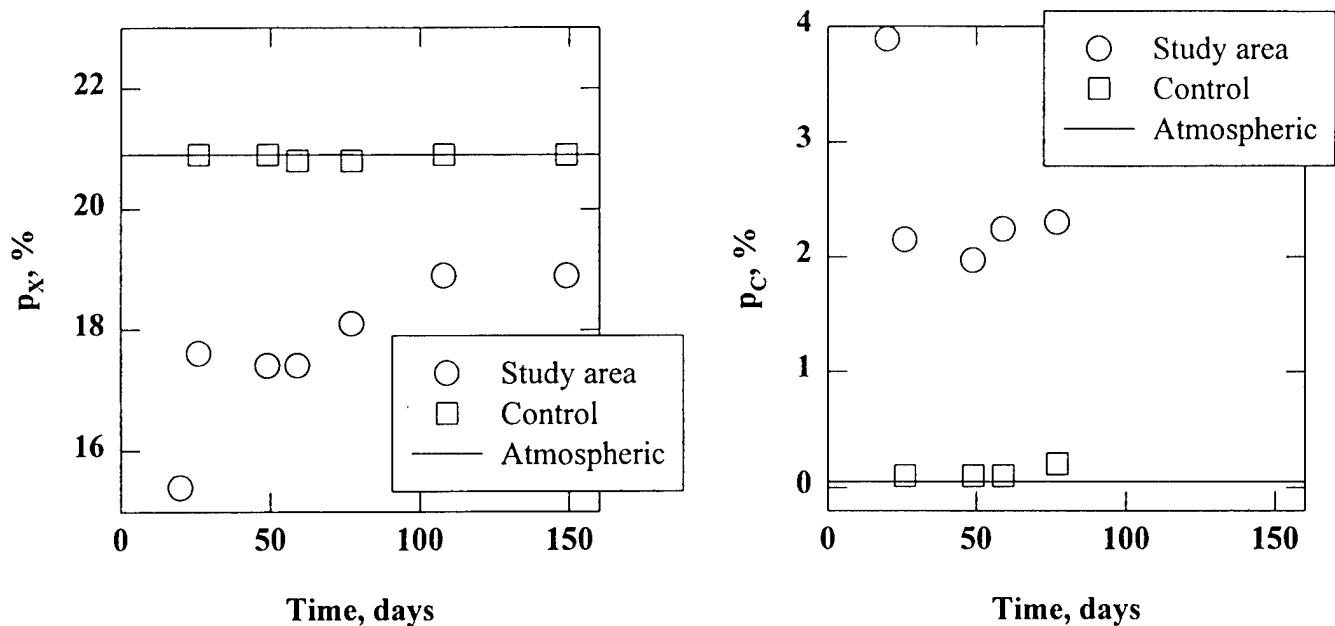


Figure 5.26 Spatial Averaged Oxygen and Carbon Dioxide Partial Pressures for Soil Venting

carbon dioxide generation ΔC to hydrocarbons ΔG degraded by soil venting. The oxygen depletion implies

$$\Delta G = \frac{\Delta X}{\gamma_X} \quad (\text{soil venting}) \quad (5.61a)$$

$$\Delta G = 0.0133 \frac{\text{kg}}{\text{m}^3} \quad (\text{oxygen depletion}) \quad (5.61b)$$

The carbon dioxide generation yields a similar estimate

$$\Delta G = \frac{\Delta C}{\gamma_C} \quad (\text{soil venting}) \quad (5.62a)$$

$$\Delta G = 0.0169 \frac{\text{kg}}{\text{m}^3} \quad (\text{carbon dioxide generation}) \quad (5.62b)$$

Our suggestion is that the hydrocarbons degrade near the capillary fringe, and so appear only at low levels in the unsaturated zone. We may add the ΔG represented by Equations 5.61 and 5.62 to the calibrated G_{INJ} value of 0.332 gm/m^3 to derive an estimate of the total hydrocarbons G_{TOTAL} stripped from the contaminated soil interval

$$G_{\text{TOTAL}} \approx G_{\text{INJ}} + \Delta G \quad (\text{soil venting}) \quad (5.63a)$$

$$G_{\text{TOTAL}} \approx 0.0154 \frac{\text{kg}}{\text{m}^3} \quad (\Delta G = 0.0151 \text{ kg/m}^3) \quad (5.63b)$$

The adopted ΔG is the average of the oxygen and carbon dioxide based estimates. We note that 98% of the hydrocarbons are degraded. We use Raoult's law to check our calculations, since the trichloroethylene is assumed to be conserved in the capillary fringe. Comparing Equations 5.51a and 5.63b, then

$$\frac{Y_{\text{INJ}}}{G_{\text{TOTAL}}} \approx 0.0097 \quad (\text{soil venting}) \quad (5.64)$$

This ratio agrees reasonably well with the saturated vapor ratio (0.019) implied by the LNAPL composition (Equation 5.53a).

5.5.2 Assimilation Capacity for Total Hydrocarbons by Soil Venting

We approximate the kinetics of soil venting near the injection point in order to infer the assimilation capacity for total hydrocarbon vapors associated with this remedial measure from the foregoing ΔG calculation. Hydrocarbon transport in the immediate vicinity of the venting wells is taken as a quasi steady balance of spherical advection and first order decay

$$Q \frac{dG}{dr'} = -2\pi r'^2 \theta \lambda G \quad (5.65a)$$

$$G = G_{\text{TOTAL}} \quad (r'=0) \quad (5.65b)$$

with constant volumetric discharge Q . We separate the variables in Equation 5.65, integrate, and solve for the first order decay constant with the result

$$\lambda = \frac{3Q}{2\pi r'^3} \ln\left(\frac{G_{\text{TOTAL}}}{G}\right) \quad (5.66)$$

The maximum assimilation capacity for hydrocarbons follows by substituting a 3 m value for r' along with G (0.332 gm/m^3) and G_{TOTAL} (15.4 gm/m^3) into Equation 5.66

$$\lambda = 3.2 \times 10^{-5} \text{ s}^{-1} \quad (\text{soil venting}) \quad (5.67)$$

These kinetics are an order of magnitude faster than the ambient rate cited in Equation 5.39b. The increase may be attributed in part to the direct introduction of oxygen into the capillary fringe, proximate to the separate phase contamination.

5.5.3 Surface Emissions

**TABLE 5.48 SURFACE EMISSIONS MEASUREMENTS
1 DECEMBER 1996**

| Location | τ , °C | North, ft | East, ft | ECD | Y | J_{YO} |
|--------------------|-------------|-----------|----------|-----------------|------------------|----------|
| Control | 5 | -200.00 | 0.00 | 78 ^a | BDL ^b | BDL |
| | 5 | -200.00 | 0.00 | 78 | BDL | BDL |
| | 5 | -200.00 | 0.00 | 208 | BDL | BDL |
| 12AK (adjacent) | 5 | 120.36 | 63.44 | 105 | BDL | BDL |
| | 5 | 120.36 | 63.44 | 73 | BDL | BDL |
| | 5 | 120.36 | 63.44 | 55 | BDL | BDL |
| 12AB (adjacent) | 9 | 126.47 | 69.54 | 86 | BDL | BDL |
| | 9 | 126.47 | 69.54 | 0 | BDL | BDL |
| | 9 | 126.47 | 69.54 | 99 | BDL | BDL |
| 12AV (adjacent) | 10 | 131.67 | 68.28 | 83 | BDL | BDL |
| | 10 | 131.67 | 68.28 | 0 | BDL | BDL |
| | 10 | 131.67 | 68.28 | 0 | BDL | BDL |
| 12AM (adjacent) | 10 | 123.88 | 77.29 | 0 | BDL | BDL |
| | 10 | 123.88 | 77.29 | 0 | BDL | BDL |
| | 10 | 123.88 | 77.29 | 0 | BDL | BDL |

^aArea units.

^bBelow detection limit.

We may estimate the flux J_{YO} of trichloroethylene vapors to the atmosphere by differentiating Equation 4.57 with the result

$$J_{YO} = w_O Y - \theta D_Y \frac{dY}{dz} \quad (z=0) \quad (5.68a)$$

$$J_{YO} = \frac{w_O Y_O}{2} \frac{\exp(\frac{w_O b_R}{2\theta D_Y})}{\sinh(\frac{w_O b_R}{2\theta D_Y}) \sqrt{1 + \frac{4\lambda_{TCE}\theta^2 D_Y}{w_O^2}}} \quad (5.68b)$$

We substitute the NAW values of Table 5.47 into Equation 5.68b and estimate a TCE emissions rate of

$$J_{YO} = 1.8 \times 10^{-6} \frac{\text{mg}}{\text{m}^2 \cdot \text{s}} \quad (\text{air sparging}) \quad (5.69a)$$

$$J_{YO} = 0.11 \frac{\mu\text{g}}{\text{m}^2 \cdot \text{min}} \quad (5.69b)$$

We deployed a surface emissions flux chamber [Tehrany et al. (1996)] at the site on 1 December 1996 to verify low TCE emissions to the atmosphere from sparging, with the results cited in Table 5.48. We detected no emissions at the site, which, in view of Equation 3.13, implies that

$$J_{YO} < 0.9 \frac{\mu\text{g}}{\text{m}^2 - \text{min}} \quad (\text{flux chamber}) \quad (5.70)$$

The observed Equation 5.70 is consistent with the theoretical Equation 5.69b.

We assess this flux in light of surface emission standards of the Federal Clear Air Act Amendments of 1990, which specify a total discharge F_{YO} of 10 tons per year of individual hazardous air pollutants and 25 tons per year of a combination of hazardous air pollutants from industrial sources. The California Air Resources Board permits 1 kg day of trichloroethylene emissions. Parsons Engineering Science (1995) estimates that the separate phase is currently spread over an areal extent A_{SPILL} of 33,000 m^2 . Collecting these standards into an allowable surface emission per unit area, we find

$$J_{YO} < \frac{F_{YO}}{A_{\text{SPILL}}} \quad (5.71a)$$

$$J_{YO} < 520 \frac{\mu\text{g}}{\text{m}^2 - \text{min}} \quad (\text{individual HAP}) \quad (5.71b)$$

$$J_{YO} < 21 \frac{\mu\text{g}}{\text{m}^2 - \text{min}} \quad (\text{TCE CARB standard}) \quad (5.71c)$$

The detection limit of our surface isolation flux chamber is three orders of magnitude lower than the emissions standard for TCE. Trichloroethylene emissions are negligible.

6 SUMMARY AND CONCLUSIONS

6.1 Summary of Work

The Civil and Environmental Engineering Department of the University of Massachusetts at Amherst (UMASS) was contracted by the United States Air Force Center for Environmental Excellence (AFCEE) to conduct field research from 19 September 1995 to 30 September 1996 under Contract No. F41624-95-C-8012 "Surface Emissions from Jet Fuel Bioventing at Plattsburgh AFB". The work focused on bioventing of residual JP4 jet fuel and chlorinated solvents in the unsaturated zone and capillary fringe beneath Fire Training Area FT-002 at the Air Force Base in Plattsburgh, NY. **UMASS tested the hypothesis that natural attenuation processes, stimulated by injected air, reduce emissions of hydrocarbons and trichloroethylene vapors to acceptable air quality standards at the site.** Drs. David W. Ostendorf, Alan J. Lutenegger, and Sarina J. Ergas were the UMASS Principal Investigators, while Patrick Haas served as AFCEE Technical Representative for the contract.

The contract was performed in four tasks: unsaturated zone characterization, soil gas and solid core sampling, maximum assimilative capacity testing, and emissions testing.

6.1.1 Unsaturated Zone Characterization

- Grain size distributions were measured at 108 depths from three boreholes. We determined moisture content profiles 785 samples from 24 boreholes completed during drilling trips on 9-13 October 1995, 30 November-1 December 1995, 5-7 June 1996, and 19-22 August 1996.
- We installed two thermocoupled arrays and measured soil temperature on 17 field sampling trips from 13 October 1995 to 19 December 1996, generating a data base of 377 observations.
- Stainless steel soil vapor probes were deployed in three boreholes on 11-13 October 1995 to determine ambient soil gas oxygen, total hydrocarbon, and carbon dioxide partial pressures across the unsaturated zone. Portable soil meters and a Tedlar bag sampling system were used to analyze the data from 38 depths in two of the boreholes, while a downhole oxygen sensor corroborated the profiles at 14 depths in the third borehole.
- We analyzed a separate phase sampled bailed from a recovery well by Base engineers to determine the composition of the residual JP4 jet fuel solvent liquid. A Hewlett Packard G1800A gas chromatograph with a mass spectrometer detector (GCD) was used to identify 84 alkanes, aromatics, and chlorinated hydrocarbons in the sample.
- UMASS personnel surveyed the plan location and mean sea level elevation of all probe profiles, clusters, arrays, and boreholes, for insertion into an AUTOCAD file for the project. Coordinates for all sample points are cited in Table 3.1.

6.1.2 Soil Gas and Solid Core Sampling

- We constructed 26 stainless steel soil gas tubing clusters to document the fate and transport of vapors through the unsaturated zone. One cluster was a control positioned well outside underlying LNAPL. The clusters were multidepth, so that 45 depths were sampled.

- The soil gas tubing clusters were sampled with portable analyzers and field installed Hewlett Packard 5890 gas chromatographs equipped with flame ionization (FID) and electron capture (ECD) detectors. We sampled soil gas oxygen, carbon dioxide, total hydrocarbons, and trichloroethylene partial pressures in Tedlar bag samples from the clusters on 17 field trips from 26 October 1995 to 19 December 1996, generating 2,083 observations.
- The vertical distribution of separate phase contamination was estimated from gas chromatographic IFD analysis of methylene chloride extracts from 785 solid core samples from 24 boreholes sampled on 9-13 October 1995, 30 November-1 December 1995, 5-7 June 1996, and 19-22 August 1996.
- The headspace of the samples was analyzed in a nitrogen glove box on line, to direct sampling efforts and delineate the contaminated interval.
- Separate phase trichloroethylene content was determined at 66 depths in six of the boreholes, using the GCD.

6.1.3 Maximum Assimilative Capacity Testing

- A soil venting system was installed in the center of the test area on 1 December 1995. The soil venting system injected heated air at a metered rate of 1 cfm into the capillary fringe, and included a helium tracer injection system. The soil was vented from 18 January 1996 to 9 August 1996, and a helium tracer was injected continuously from 7 February to 7 March 1996.
- We measured vented helium in 31 of the stainless steel tubing cluster sampling points on 13 February and 21 February 1996 to document the pneumatics of the soil venting. A field installed Hewlett Packard 5890 gas chromatograph with thermal conductivity detector (TCD) was used to measure the helium in Tedlar bag samples.
- An air sparging system was built in the center of the test area on 1 December 1995 as well. The air sparging system injected heated air 1.2 m below the water table from 9 August to 5 September 1996 and from 24 October to 19 December 1996. A helium tracer was injected continuously from 24 October to 24 November 1996.
- We measured helium in 35 of the stainless steel tubing cluster sampling points on 7 November and 29 November 1996, using the TCD gas chromatograph.
- A finite element model with supplemental analytical subroutines was used to model the stainless steel tubing cluster and vapor probe data. The model was tested with the helium tracer data, followed by soil gas data calibrations to determine the maximum assimilative capacity of the unsaturated zone for hydrocarbon and trichloroethylene vapor degradation. Air and total porosities were input from the moisture content data, and soil temperature was modeled with a constant diffusivity analysis.

6.1.4 Emissions Testing

- We installed two near surface arrays to measure helium and TCE profiles through the root zone. The arrays were of stainless steel construction, with a low sample volume facilitating sampling on 5 cm vertical spacing. Fourteen depths were established at each array.
- We analyzed helium and trichloroethylene soil gas concentrations on 20 November 1996 using field installed gas chromatographs with TCD and ECD detectors.

- We measured soil gas oxygen, total hydrocarbons, carbon dioxide, and trichloroethylene partial pressures near the capillary fringe using a soil vapor probe during air sparging. Eighty one depths were sampled in seven boreholes on 21-22 August 1996, using portable meters and a field installed FID equipped gas chromatograph.
- The near surface array data were input to an analytical model of soil gas transport through the root zone. The helium data calibrated the pneumatics, while the TCE data were used to calibrate the capacity of the root zone to assimilate TCE vapors.
- A surface isolation flux chamber was designed, built, and deployed, to verify low levels of emissions from the site area.

6.2 Conclusions

This extensive field sampling, laboratory analysis, and mathematical modeling efforts tests the hypothesis with the following result: **natural attenuation processes reduce emissions of hydrocarbon and trichloroethylene vapors to acceptable air quality standards at the site.**

We support this general conclusion with particular results:

- **A significant mass of separate phase petroleum persists in and immediately below the capillary fringe.** We found total petroleum hydrocarbon levels as high as 26,400 mg TPH/kg dry soil (borehole 12AS), with contaminated intervals ranging from 1.1 to 2.54 m in extent (Table 5.6). The distribution is unimodal, and is reasonably described by capillary scaling theory (Figure 5.7). A significant fraction of the LNAPL is residually bound to the soil (as much as 7,000 mg TPH/kg dry soil). The separate phase is well correlated with the headspace concentrations.
- **Separate phase trichloroethylene occurs at levels as high as 59 mg TCE/kg dry soil immediately below the capillary fringe (Table 5.7).** The ratio of separate phase TCE to total LNAPL in 95 samples is 0.0025, yielding a separate phase mole fraction of 0.00222 and a saturated TCE vapor pressure of 170 ppm.
- **Soil gas oxygen and carbon dioxide concentrations suggest a maximum assimilative capacity of $1.4 \times 10^{-6} \text{ s}^{-1}$ under ambient conditions near the capillary fringe (Equation 5.39b).** This capacity is based on high, stoichiometrically coupled fluxes of oxygen entering and carbon dioxide leaving the fringe by ambient diffusion.
- **Soil gas oxygen and carbon dioxide concentrations suggest that soil venting increases the maximum assimilative capacity near the capillary fringe to $3.2 \times 10^{-5} \text{ s}^{-1}$ (Equation 5.67).** This capacity is based on a comparison of soil gas concentrations in study area with those observed at the control cluster.
- **We see little evidence of hydrocarbons or of hydrocarbon degradation in the unsaturated zone, although trichloroethylene exists at significant levels.** The finite element code, calibrated with tubing cluster data, suggests that trichloroethylene comprises a disproportionately high fraction of the hydrocarbon vapors found in the stainless steel tubing clusters under ambient, soil venting (Equation 5.53b), or air sparging (Equation 5.56b) conditions. The observed TCE concentrations are consistent with the saturated vapor pressure implied by Raoult's law, while the hydrocarbon pressures are two orders of magnitude lower than values expected in the absence of degradation. **These findings, together with the observed fluxes of**

oxygen and carbon dioxide, support the hypothesis that JP4 hydrocarbon vapors degrade aerobically near the capillary fringe.

- **Trichloroethylene vapors degrade in the root zone, at a maximum assimilative capacity of $2.0 \times 10^{-6} \text{ s}^{-1}$ (Equation 5.59).** This conclusion reflects calibration of quasi steady vertical transport models for abiotic helium (Equation 5.58) and first order decaying trichloroethylene (Equation 4.57) with replicated near surface array data (Tables 5.46, 5.47 and Figure 5.25). These data were gathered late in the study period, after seven months of soil venting and two months of air sparging.
- **No detectable trichloroethylene was emitted to the atmosphere.** We base this conclusion on a computed flux rate of $0.11 \text{ } \mu\text{g}/\text{m}^2\text{-min}$ (Equation 5.69b), confirmed by emissions testing at the site using the flux chamber.

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APPENDIX I BOREHOLE LOGS

3" Spoon Data

| | | | | | |
|---------------------|---|----------|---------|----------|------------------------------|
| Site Location: | Plattsburgh AFB | | | | |
| Date: | 10/09/95 | | | | |
| Personnel on site: | S.Kelley, C. Riccardi, T. Mitchell, A. Lutenegger, D. Ostendorf, P. Terrany, R. Suchana, E. Hinlein, M. McGrath, B. Chakow, P. Reyes, R. Miknis | | | | |
| Drillers: | CTB - Steve, Johnny | | | | |
| <div>12AA</div> | | | | | |
| Boring Information: | Semi-continuous sampling from surface (every 5') | | | | |
| Rods used: | NWJ | | | | |
| SPT Protocol: | Automatic 140 lb. hammer with a 30" drop height | | | | |
| Location: | Center of transects | | | | |
| Core # | Depth (ft) | Blows/6" | N-value | Recovery | notes |
| 1 | 0-1.5 | 3-6-7 | 13 | 16 | |
| 2 | 5-6.5 | 4-4-5 | 9 | 16 | dark brown sand |
| 3 | 10.0-11.5 | 10-14-17 | 31 | 20.5 | light brown sand |
| 4 | 15.0-16.5 | 13-21-24 | 45 | 18.5 | |
| 5 | 20.0-21.5 | 5-8-8 | 16 | 19 | light brown sand |
| 6 | 25.0-26.5 | 6-8-10 | 18 | 18.5 | |
| 7 | 30.0-31.5 | 6-14-18 | 32 | 20 | |
| 8 | 35.0-36.5 | 9-12-12 | 24 | 19 | |
| 9 | 36.5-38.0 | 7-13-15 | 28 | 19 | |
| 10 | 38.0-39.5 | 8-12-13 | 25 | 18 | |
| 11 | 39.5-41.0 | 9-10-12 | 22 | 15 | |
| 12 | 41.0-42.5 | 4-9-11 | 20 | 17.5 | |
| 13 | 42.5-44.0 | 16-7-9 | 18 | 17 | |
| 14 | 44.0-45.5 | 11-9-16 | 25 | 13.5 | |
| 15 | 45.5-47.0 | 3-5-5 | 10 | 8 | |
| 16 | 47.0-48.5 | 9-10-14 | 24 | 13 | Water used inside |
| 17 | 48.5-50.0 | 4-6-9 | 15 | 11 | augers to keep borehole open |
| 18 | 50.0-51.5 | 4-4-8 | 12 | 0 | |

3" Spoon Data

| | |
|--------------------|--|
| Site Location: | Plattsburgh AFB |
| Date: | 10/09/95 |
| Personnel on site: | S.Kelley, C. Riccardi, T. Mitchell, A. Lutenegger, D. Ostendorf, P. Terrany, R. Suchana, E. Hinlein, M. McGrath, B. Chakow, P. Reyes, R. Miknis |
| Drillers: | CTB - Steve, Johnny |

12AB

| | |
|---------------------|--|
| Boring Information: | Auger to 35' and sample semi-continuous (every 5') |
| Rods used: | NWJ |
| SPT Protocol: | Automatic 140 lb. hammer with a 30" drop height |
| Location: | 5' south west of 12AA |

| Core # | Depth (ft) | Blows/6" | N-value | Recovery | notes |
|--------|------------|----------|---------|----------|------------------------------|
| 1 | 35-36.5 | 11-14-15 | 29 | 18 | |
| 2 | 40-41.5 | 2-4-7 | 11 | 14 | Water used inside |
| 3 | 45-46.5 | 5-8-15 | 23 | 11.5 | augers to keep borehole open |
| 4 | 50-51.5 | 4-7-12 | 19 | 0 | |

3" Spoon Data

| | | | | | |
|---------------------|--|----------|---------|----------|---|
| Site Location: | Plattsburgh AFB | | | | |
| Date: | 34982 | | | | |
| Personnel on site: | S.Kelley, C. Riccardi, T. Mitchell, A. Lutenegger, D. Ostendorf, S. Ergas, P. Terrany, R. Suchana, E. Hinlein, M. McGrath, B. Chakow, P. Reyes, R. Miknis, P.Cheever | | | | |
| Drillers: | CTB - Steve, Johnny | | | | |
| 12AD | | | | | |
| Boring Information: | Semi-continuous sampling from surface (every 5'), Continuous sampling 35'-48' | | | | |
| Rods used: | NWJ | | | | |
| SPT Protocol: | Automatic 140 lb. hammer with a 30" drop height | | | | |
| Location: | 15' North of 12AA | | | | |
| Core # | Depth (ft) | Blows/6" | N-value | Recovery | notes |
| 1 | 0-1.5 | 3-3-5 | 8 | 18 | |
| 2 | 5-6.5 | 3-3-4 | 7 | 11 | |
| 3 | 10.0-11.5 | 10-13-15 | 28 | 19 | |
| 4 | 15.0-16.5 | 11-16-18 | 34 | 20 | |
| 5 | 20.0-21.5 | 8-11-11 | 22 | 19 | |
| 6 | 25.0-26.5 | 6-10-12 | 22 | 18 | |
| 7 | 30.0-31.5 | 9-13-16 | 29 | 18 | |
| 8 | 35.0-36.5 | 7-8-8 | 16 | 17 | |
| 9 | 36.5-38.0 | 6-6-8 | 14 | 17 | |
| 10 | 38.0-39.5 | 3-4-5 | 9 | 16 | |
| 11 | 39.5-41.0 | 30-9-5 | 14 | 16 | |
| 12 | 41.0-42.5 | 3-4-5 | 9 | 3 | |
| 13 | 42.5-44.0 | 3-5-6 | 11 | 0 | Since no recovery changed to a 2" SS (24" long) |
| 14 | 44.0-46.0 | 2-3-3-7 | 6 | 18 | 24" drive |
| 15 | 46.0-48.0 | 2-3-5-6 | 8 | 14 | 24" drive |
| End of Boring | | | | | |

3" Spoon Data

| | | | | | |
|---------------------|--|----------|---------|----------|--|
| Site Location: | Plattsburgh AFB | | | | |
| Date: | 10/10/95 | | | | |
| Personnel on site: | S.Kelley, C. Riccardi, T. Mitchell, A. Lutenegger, D. Ostendorf, S. Ergas, P. Terrany, R. Suchana, E. Hinlein, M. McGrath, B. Chakow, P. Reyes, R. Miknis, P.Cheever | | | | |
| Drillers: | CTB - Steve, Johnny | | | | |
| 12AG | | | | | |
| Boring Information: | Semi-continuous sampling from surface (every 5'), Continuous sampling 35'-48' | | | | |
| Rods used: | NWJ | | | | |
| SPT Protocol: | Automatic 140 lb. hammer with a 30" drop height | | | | |
| Location: | 25' North of 12AA | | | | |
| Core # | Depth (ft) | Blows/6" | N-value | Recovery | notes |
| 1 | 0-1.5 | 3-4-3 | 7 | 18 | |
| 2 | 5-6.5 | WOH-1-1 | 2 | 7 | |
| 3 | 10.0-11.5 | 1-1-1 | 2 | 18 | |
| 4 | 15.0-16.5 | 6-10-11 | 21 | 18 | |
| 5 | 20.0-21.5 | 5-8-8 | 16 | 19 | |
| 6 | 25.0-26.5 | 5-12-13 | 25 | 18 | |
| 7 | 30.0-31.5 | 4-9-13 | 22 | 18 | |
| 8 | 35.0-36.5 | 5-8-9 | 17 | 18 | |
| 9 | 36.5-38.0 | 4-6-6 | 12 | 18 | |
| 10 | 38.0-39.5 | 5-5-6 | 11 | 16 | |
| 11 | 39.5-41.0 | 4-5-6 | 11 | 20 | |
| 12 | 41.0-42.5 | 5-7-7 | 14 | 18 | |
| 13 | 42.5-44.0 | 3-5-8 | 13 | 0 | Since no recovery changed to a 2" SS (24" long |
| 14 | 44.0-46.0 | 3-4-5-8 | 9 | 9 | 24" drive |
| 15 | 46.0-48.0 | 2-5-6-7 | 11 | 16 | 24" drive |
| End of Boring | | | | | |

3" Spoon Data

| | | | | | |
|---------------------|---|----------|---------|----------|--|
| Site Location: | Plattsburgh AFB | | | | |
| Date: | 10/11/95 | | | | |
| Personnel on site: | S.Kelley, C. Riccardi, T. Mitchell, D. Ostendorf, P. Terrany, R. Suchana, E. Hinlein, M. McGrath, P. Reyes, R. Miknis, P.Cheever | | | | |
| Drillers: | CTB - Steve, Johnny | | | | |
| <div>12AK</div> | | | | | |
| Boring Information: | Semi-continuous sampling from surface (every 5'), Continuous sampling 35'-48' | | | | |
| Rods used: | NWJ | | | | |
| SPT Protocol: | Automatic 140 lb. hammer with a 30" drop height | | | | |
| Location: | 15' Southwest of 12AA | | | | |
| Core # | Depth (ft) | Blows/6" | N-value | Recovery | notes |
| 1 | 0-1.5 | 4-5-6 | 11 | 16 | |
| 2 | 1.5-3.0 | 5-3-3 | 6 | 16 | |
| 3 | 5-6.5 | 3-8-7 | 15 | 15 | |
| 4 | 10.0-11.5 | 4-6-10 | 16 | 18 | |
| 5 | 15.0-16.5 | 11-18-20 | 38 | 19 | |
| 6 | 20.0-21.5 | 6-8-10 | 18 | 19 | |
| 7 | 25.0-26.5 | 7-10-11 | 21 | 19 | |
| 8 | 30.0-31.5 | 4-8-12 | 20 | 18 | |
| 9 | 35.0-36.5 | 11-15-16 | 31 | 19 | |
| 10 | 36.5-38.0 | 4-11-13 | 24 | 23 | |
| 11 | 38.0-39.5 | 5-7-10 | 17 | 18 | |
| 12 | 39.5-41.0 | 12-5-7 | 12 | 17 | |
| 13 | 41.0-43.0 | 2-5-6-8 | 11 | 20/24 | 24" drive with water as drilling fluid |
| 14 | 43.0-45.0 | 3-5-6-7 | 11 | 20/24 | 24" drive with water as drilling fluid |
| 15 | 45.0-47.0 | 1-3-5-7 | 8 | 21/24 | 24" drive with water as drilling fluid |
| End of Boring | | | | | |

3" Spoon Data

| | |
|--------------------|--|
| Site Location: | Plattsburgh AFB |
| Date: | 10/12/95 |
| Personnel on site: | S.Kelley, C. Riccardi, T. Mitchell, P.Cheever R. Suchana, E. Hinlein, M. McGrath, P. Reyes, R. Miknis |
| Drillers: | CTB - Steve, Johnny |

12AM

| | |
|---------------------|---|
| Boring Information: | Auger down to 35', Continuous sampling 35'-48' |
| Rods used: | NWJ |
| SPT Protocol: | Automatic 140 lb. hammer with a 30" drop height |
| Location: | 5' Northwest of 12AA |

| Core # | Depth (ft) | Blows/6" | N-value | Recovery | notes |
|--------|------------|----------|---------|----------|--|
| 1 | 35.0-36.5 | 9-13-15 | 28 | 19 | |
| 2 | 36.5-38.0 | 12-13-16 | 29 | 19 | |
| 3 | 38.0-39.5 | 7-10-11 | 21 | 18 | |
| 4 | 39.5-41.0 | 7-5-8 | 13 | 21 | |
| 5 | 41.0-43.0 | 3-4-7-9 | 11 | 18/24 | 24" drive with water as drilling fluid |
| 6 | 43.0-45.0 | 3-5-6-8 | 11 | 19/24 | 24" drive with water as drilling fluid |
| 7 | 45.0-47.0 | 4-6-8-8 | 14 | 18/24 | 24" drive with water as drilling fluid |

End of Boring

3" Spoon Data

| | | | | | |
|----------------------|--|-----------------|----------------|-----------------|--|
| Site Location: | Plattsburgh AFB | | | | |
| Date: | 34985 | | | | |
| Personnel on site: | S.Kelley, C. Riccardi, T. Mitchell, P.Cheever R. Suchana, E. Hinlein, M. McGrath, P. Reyes, R. Miknis | | | | |
| Drillers: | CTB - Steve, Johnny | | | | |
| 12AP | | | | | |
| Boring Information: | Auger down to 35', Continuous sampling 35'-48' | | | | |
| Rods used: | NWJ | | | | |
| SPT Protocol: | Automatic 140 lb. hammer with a 30" drop height | | | | |
| Location: | 12' East of 12AA | | | | |
| | | | | | |
| Core # | Depth (ft) | Blows/6" | N-value | Recovery | notes |
| 1 | 35.0-36.5 | 7-13-11 | 24 | 19 | |
| 2 | 36.5-38.0 | 15-12-14 | 26 | 19 | |
| 3 | 38.0-39.5 | 10-13-15 | 28 | 19 | |
| 4 | 39.5-41.0 | 3-7-12 | 29 | 18 | |
| 5 | 41.0-43.0 | 7-9-13-13 | 22 | 17/24 | 24" drive with water as drilling fluid |
| 6 | 43.0-45.0 | 2-7-10-12 | 17 | 17/24 | 24" drive with water as drilling fluid |
| End of Boring | | | | | |

3" Spoon Data

| | |
|--------------------|--|
| Site Location: | Plattsburgh AFB |
| Date: | 10/13/95 |
| Personnel on site: | S.Kelley, C. Riccardi, T. Mitchell, P.Cheever R. Suchana, E. Hinlein, M. McGrath, P. Reyes, R. Miknis |
| Drillers: | CTB - Steve, Johnny |

12AR

| | |
|---------------------|---|
| Boring Information: | Auger down to 35', Continuous sampling 35'-48' |
| Rods used: | NWJ |
| SPT Protocol: | Automatic 140 lb. hammer with a 30" drop height |
| Location: | 15' Northeast of 12AA |

| Core # | Depth (ft) | Blows/6" | N-value | Recovery | notes |
|--------|------------|----------|---------|----------|--|
| 1 | 35.0-36.5 | 6-8-12 | 20 | 18 | |
| 2 | 36.5-38.0 | 7-8-8 | 16 | 16 | |
| 3 | 38.0-39.5 | 1-1-1 | 2 | 17 | |
| 4 | 39.5-41.0 | 12-5-4 | 9 | 16 | |
| 5 | 41.0-43.0 | 4-5-6-14 | 11 | 21/24 | 24" drive with water as drilling fluid |
| 6 | 43.0-45.0 | 1-2-4-5 | 6 | 12/24 | 24" drive with water as drilling fluid |
| 7 | 45.0-47.0 | 2-4-7-9 | 11 | 16/24 | 24" drive with water as drilling fluid |

End of Boring

3" Spoon Data

| | | | | | |
|---------------------|--|-----------|---------|----------|-----------------|
| Site Location: | Plattsburgh AFB | | | | |
| Date: | 12/2/95 | | | | |
| Personnel on site: | S.Kelley, Dr. Lutenegger, Dr. DeGroot, T. Mitchell, G. Costa R. Mikinis, R. Suchana, P.Reyes, B.Glass, Chris, B. Charkhow P. Tehrany, D. Ostendorf, E. Hinlein | | | | |
| Drillers: | CTB - Steve and Johnny | | | | |
| | | 12AS | | | |
| Boring Information: | Augered to 35' (with 3 1/4" augers) and sample continuous from 35' to 49.0' | | | | |
| Rods used: | NWJ | | | | |
| SPT Protocol: | Automatic 140 lb. hammer with a 30" height | | | | |
| Location: | 5' south of 12AA | | | | |
| | | | | | |
| Core # | Depth (ft) | Blows/6" | N-value | Recovery | notes |
| 1 | 35.0-36.5 | 9-10-14 | 24 | 18 | |
| 2 | 36.5-38.0 | 8-11-13 | 24 | 18 | |
| 3 | 38.0-39.5 | 10-8-7 | 15 | 18 | water at 39.5' |
| 4 | 39.5-41.0 | 16-7-9 | 16 | 18 | |
| 5 | 41.0-42.5 | 8-12-20 | 32 | 18 | |
| 6 | 42.5-44.0 | 12-16-19 | 35 | 14 | pour 2 bkts H2O |
| 7 | 44.0-45.5 | 9-12-15 | 27 | 12 | |
| 8 | 45.5-47.0 | 4-5-8 | 13 | 0 | pour 2 bkts H2O |
| 9 | 45.5-47.0 | 1-3-4 | 7 | 18 | 2" split spoon |
| 10 | 47.0-49.0 | 4-7-10-30 | 17 | 24 | pour 2 bkts H2O |

3" Spoon Data

| | | | | | |
|---------------------|---|----------|---------|----------|--------------------|
| Site Location: | Plattsburgh AFB | | | | |
| Date: | 12/1/95 | | | | |
| Personnel on site: | S.Kelley, Dr. Lutenegeger, Dr. DeGroot, T. Mitchell, G. Costa R. Mikinis, R. Suchana, P.Reyes, B.Glass, Chris, B. Charkhow P. Tehrany, D. Ostendorf, E. Hinlein | | | | |
| Drillers: | CTB - Steve and Johnny | | | | |
| | 12AT | | | | |
| Boring Information: | Augered to 25' (with 3 1/4" augers) and sample continuous from 35' to 40.5' | | | | |
| Rods used: | NWJ | | | | |
| SPT Protocol: | Automatic 140 lb. hammer with a 30" height | | | | |
| Location: | 200' south of 12AA | | | | |
| | | | | | |
| Core # | Depth (ft) | Blows/6" | N-value | Recovery | notes |
| 1 | 25.0-26.5 | 8-10-10 | 20 | 18 | |
| 2 | 30.0-31.5 | 6-12-11 | 23 | 18 | |
| 3 | 31.5-33.0 | 5-10-11 | 21 | 18 | |
| 4 | 33.0-34.5 | 5-8-12 | 20 | 18 | |
| 5 | 34.5-36.0 | 21-10-11 | 21 | 18 | |
| 6 | 36.0-37.5 | 6-16-19 | 35 | 18 | |
| 7 | 37.5-39.0 | 9-13-16 | 29 | 12.5 | used water to keep |
| 8 | 39.0-40.5 | 13-16-16 | 32 | 14 | hole open |

3" Spoon Data

| | | | | | |
|---------------------|--|---------------|---------|---------------|--------------------------------|
| Site Location: | Plattsburgh AFB | | | | |
| Date: | 06/05/96 | | | | |
| Personnel on site: | S.Kelley, Dr. Lutenegger, T.Mitchell, G.Costa, T.Thomson, M. Rodick, J. Clary E. Hinlein, B. Charkow, B. Glass, T. Scheonberg, DaveO. | | | | |
| Drillers: | CTB - Steve, Johnny | | | | |
| <div>12AU</div> | | | | | |
| Boring Information: | Augered to 38' (with 3 1/4" augers) and sample continuous from 38' to 53' | | | | |
| Rods used: | NWJ | | | | |
| SPT Protocol: | 3" Barrel sampler driven with an automatic 140 lb. hammer with a 30" drop height | | | | |
| Location: | 8' in from 12AA perpendicular to fence. | | | | |
| | | | | | |
| Core # | Depth (ft) | Blows/6" | N-value | Recovery (in) | notes |
| 1 | 38.0-39.5 | 5-5-6 | 11 | 17 | |
| 2 | 39.5-41.0 | 13-6-9 | 15 | 23.5 | |
| 3 | 41.0-42.5 | 9-9-11 | 20 | 0 | Switched to a 2" SS with water |
| 4 | 42.5-44.0 | 2-4-6 | 10 | 0 | |
| 5 | 44.0-45.5 | 3-5-27 | 32 | 15.5 | |
| 6 | 45.5-47.0 | 3-4-6 | 10 | 13 | |
| 7 | 47.0-49.0 | 3-3-6-7 | 9 | 17.5 | Driven 24" |
| 8 | 49.0-53.0 | 2-3-3-7-11-12 | N/A | 34 | Driven 4' |

3" Spoon Data

| Site Location: | Plattsburgh AFB | | | | |
|---------------------|--|----------|---------|---------------|--------------------------|
| Date: | 06/05/96 | | | | |
| Personnel on site: | S.Kelley, Dr. Lutenegger, T.Mitchell, G.Costa, T.Thomson, M. Rodick E. Hinlein, B. Charkow, B. Glass, T. Scheonberg, DaveO. | | | | |
| Drillers: | CTB - Steve, Johnny | | | | |
| 12AV | | | | | |
| Boring Information: | Augered to 35' (with 3 1/4" augers) and sample continuous from 35' to 49' | | | | |
| Rods used: | NWJ | | | | |
| SPT Protocol: | 3" Barrel sampler driven 18" with an automatic 140 lb. hammer with a 30" drop height | | | | |
| Location: | 6' Southwest of AA | | | | |
| | | | | | |
| Core # | Depth (ft) | Blows/6" | N-value | Recovery (in) | notes |
| 3 | 35.0-36.5 | 4-7-6 | 13 | 20 | 3" core Drive 18" |
| 4 | 36.5-38.0 | 3-4-4 | 8 | 18.5 | |
| 5 | 38.0-39.5 | 3-3-3 | 6 | 16 | |
| 6 | 39.5-41.0 | 12-4-4 | 8 | 13.5 | |
| 7 | 41.0-42.5 | 5-9-18 | 27 | 0 | Add water in augers |
| 8 | 43.0-45.0 | 2-3-3-14 | 17 | 19.5 | 2" split spoon Drive 24" |
| 9 | 45.0-47.0 | 1-2-2-3 | 5 | 22 | |
| 10 | 47.0-49.0 | 1-1-2-2 | 4 | 17.5 | |

3" Spoon Data

| | | | | | |
|---------------------|--|----------|---------|---------------|-------------------------------|
| Site Location: | Plattsburgh AFB | | | | |
| Date: | 06/05/96 | | | | |
| Personnel on site: | S.Kelley, Dr. Lutenegger, T.Mitchell, G.Costa, T.Thomson, M. Rodick E. Hinlein, B. Charkow, B. Glass, T. Scheonberg, DaveO. | | | | |
| Drillers: | CTB - Steve, Johnny | | | | |
| <div>12AW</div> | | | | | |
| Boring Information: | Augered to 35' (with 3 1/4" augers) and sample continuous from 35' to 48.5' | | | | |
| Rods used: | NWJ | | | | |
| SPT Protocol: | 3" Barrel sampler driven 18" with an automatic 140 lb. hammer with a 30" drop height | | | | |
| Location: | Midway between 12AC and 12AD | | | | |
| | | | | | |
| Core # | Depth (ft) | Blows/6" | N-value | Recovery (in) | notes |
| 1 | 35.0-36.5 | 5-11-14 | 25 | 18 | 3" barrel, Drive 18" |
| 2 | 36.5-38.0 | 8-8-8 | 16 | 16 | |
| 3 | 38.0-39.5 | 5-4-6 | 10 | 16.5 | |
| 4 | 39.5-41.0 | 8-5-5 | 10 | 18 | Used water to keep sand out |
| 5 | 41.0-42.5 | 6-10-17 | 27 | 12 | |
| 6 | 42.5-44.5 | 2-2-4-5 | 9 | 17 | Switched to a 2" Split Spoon, |
| 7 | 44.6-46.5 | 1-2-4-6 | 10 | 16 | Drive 24" |
| 8 | 46.5-48.5 | 3-4-7-9 | 16 | 17 | |

3" Spoon Data

| | |
|--------------------|---|
| Site Location: | Plattsburgh AFB |
| Date: | 06/06/96 |
| Personnel on site: | S.Kelley, T.Mitchell, M. Rodick, J.Clary E. Hinlein, B. Charkow, B. Glass, T. Scheonberg, DaveO. |
| Drillers: | CTB - Steve, Johnny |

12AX

| | |
|---------------------|--|
| Boring Information: | Augered to 35' (with 3 1/4" augers) and sample continuous from 5' to 37.0' |
| Rods used: | NWJ |
| SPT Protocol: | 3" Barrel sampler driven 18" with an automatic 140 lb. hammer with a 30" drop height |
| Location: | 6'10" South of Barometric well |

| Core # | Depth (ft) | Blows/6" | N-value | Recovery (in) | notes |
|--------|------------|----------|---------|---------------|-----------------------|
| 1 | 5.0-6.5 | 5-6-5 | 11 | 17 | 3" barrel, Drive 18" |
| 2 | 6.5-8.0 | 4-10-10 | 20 | 17 | |
| 3 | 8.0-9.5 | 6-8-11 | 19 | 18 | |
| 4 | 9.5-11.0 | 8-8-12 | 20 | 20 | |
| 5 | 11.0-12.5 | 6-8-7 | 15 | 16 | |
| 6 | 12.5-14.0 | 5-5-6 | 11 | 14 | |
| 7 | 14.0-15.5 | 5-8-7 | 15 | 17 | |
| 8 | 15.5-17.0 | 3-8-8 | 16 | 16 | |
| 9 | 17.0-18.5 | 6-8-10 | 18 | 20.5 | |
| 10 | 18.5-20.0 | 3-6-6 | 12 | 14 | |
| 11 | 20.0-21.5 | 5-5-9 | 14 | 18 | |
| 12 | 21.5-23.0 | 6-9-9 | 18 | 18 | |
| 13 | 23.0-24.5 | 4-6-8 | 14 | 18 | |
| 14 | 24.5-26.0 | 3-7-7 | 14 | 17 | |
| 15 | 26.0-27.5 | 7-10-11 | 21 | 20 | |
| 16 | 27.5-29.0 | 3-8-13 | 21 | 15.5 | |
| 17 | 29.0-30.5 | 7-10-10 | 20 | 19 | |
| 18 | 30.5-32.0 | 5-7-9 | 16 | 17 | Sample is fairly wet. |
| 19 | 32.0-33.5 | 7-7-6 | 13 | 17 | Sample is wet. |
| 20 | 33.5-35.0 | 4-6-10 | 16 | 16 | Adding water. |
| 21 | 35.0-36.5 | 3-5-8 | 13 | 12 | |
| 22 | 36.5-37.0 | 5-10-14 | 24 | 0 | |

2" Spoon Data

| Site Location: | Plattsburgh AFB | | | | |
|---------------------|---|-------------|---------|---------------|---|
| Date: | 06/06/96 | | | | |
| Personnel on site: | S. Kelley, T. Mitchell, M. Rodick, J. Clary E. Hinlein, B. Charkhow, B. Glass, T. Schoenberg, Dave Ostendorf | | | | |
| Drillers: | CTB - Steve, Johnny | | | | |
| | 12AY | | | | |
| Boring Information: | Samples continuous from 0' to 45.0' | | | | |
| Rods used: | NWJ | | | | |
| SPT Protocol: | 2" split spoon (unlined) sampler driven with an automatic 140 lb. hammer with a 30" drop height | | | | |
| Location: | 24' Southeast of SPK1 | | | | |
| | | | | | |
| Core # | Depth (ft) | Blows/6" | N-value | Recovery (in) | notes |
| 1 | 0-2.0 | 1-2-2-2 | 4 | 23 | |
| 2 | 2.0-4.0 | 2-1-1-2 | 3 | 21.5 | |
| 3 | 4.0-6.0 | 5-5-6-8 | 14 | 24 | |
| 4 | 6.0-8.0 | 5-7-7-10 | 17 | 19 | |
| 5 | 8.0-10.0 | 7-10-14-13 | 27 | 14 | |
| 6 | 10.0-12.0 | 6-9-11-12 | 23 | 26 | |
| 7 | 12.0-14.0 | 8-10-11-13 | 24 | 24 | |
| 8 | 14.0-16.0 | 7-9-10-14 | 24 | 23 | |
| 9 | 16.0-18.0 | 6-6-8-12 | 20 | 23.5 | |
| 10 | 18.0-20.0 | 4-7-10-10 | 20 | 22.5 | |
| 11 | 20.0-22.0 | 5-8-8-10 | 18 | 25 | |
| 12 | 22.0-24.0 | 5-8-8-18 | 26 | 24 | |
| 13 | 24.0-26.0 | 6-6-8-8 | 16 | 23 | |
| 14 | 26.0-28.0 | 8-6-6-8 | 14 | 24 | |
| 15 | 28.0-30.0 | 6-7-7-8 | 15 | 26 | |
| 16 | 30.0-32.0 | 5-7-8-12 | 20 | 24 | |
| 17 | 32.0-34.0 | 10-14-18-19 | 37 | 23 | |
| 18 | 34.0-36.0 | 9-14-11-11 | 22 | 23 | Switched to a 3" Core Sampler, 18" Drives. |
| 19 | 36.0-37.5 | 10-12-17 | 29 | 19 | |
| 20 | 37.5-39.0 | 4-10-14 | 24 | 18 | |
| 21 | 39.0-40.5 | 7-11-10 | 21 | 22 | Switched to a 2" split spoon. |
| 22 | 41.0-43.0 | 2-4-6-7 | 13 | 15 | |
| 23 | 43.0-45.0 | 6-6-9-10 | 19 | 12 | |

3" Spoon Data

| | |
|--------------------|--|
| Site Location: | Plattsburgh AFB |
| Date: | 06/07/96 |
| Personnel on site: | S.Kelley, T.Mitchell, M. Rodick E. Hinlein, B. Charkow, B. Glass, T. Scheonberg |
| Drillers: | CTB - Steve, Johnny |

12AZ

| | |
|---------------------|--|
| Boring Information: | Augered to 35' (with 3 1/4" augers) and sample continuous from 35' to 51.0' |
| Rods used: | NWJ |
| SPT Protocol: | 3" Barrel sampler driven 18" with an automatic 140 lb. hammer with a 30" drop height |
| Location: | 5' Northwest of SPK1 |

| Core # | Depth (ft) | Blows/6" | N-value | Recovery (in) | notes |
|--------|------------|----------|---------|---------------|--------------------------------|
| 1 | 35.0-36.5 | 5-11-12 | 23 | 18 | 3" barrel, 18" drives |
| 2 | 36.5-38.0 | 10-12-15 | 27 | 18 | |
| 3 | 38.0-39.5 | 5-5-8 | 13 | 18 | |
| 4 | 39.5-41.0 | 7-17-23 | 40 | 18 | |
| 5 | 41.0-43.0 | 5-6-7-9 | 13 | 18 | 2" spilt spoon, 24" drives |
| 6 | 43.0-45.0 | 3-5-6-9 | 11 | 19 | used water to keep static head |
| 7 | 45.0-47.0 | 2-5-7-9 | 12 | 14 | |
| 8 | 47.0-49.0 | 3-5-8-8 | 13 | 18 | |
| 9 | 49.0-51.0 | 9-10-4-5 | 14 | 24 | |

3" Spoon Data

| | | | | | |
|---------------------|--|------------|---------|---------------|--------------------------------|
| Site Location: | Plattsburgh AFB | | | | |
| Date: | 06/07/96 | | | | |
| Personnel on site: | S.Kelley, T.Mitchell, M. Rodick E. Hinlein, B. Charkow, B. Glass, T. Scheonberg | | | | |
| Drillers: | CTB - Steve, Johnny | | | | |
| <div>12BA</div> | | | | | |
| Boring Information: | Augered to 35' (with 3 1/4" augers) and sample continuous from 35' to 53.0' | | | | |
| Rods used: | NWJ | | | | |
| SPT Protocol: | 3" Barrel sampler driven 18" with an automatic 140 lb. hammer with a 30" drop height | | | | |
| Location: | 4' Northwest of 12AP | | | | |
| | | | | | |
| Core # | Depth (ft) | Blows/6" | N-value | Recovery (in) | notes |
| 1 | 35.0-36.5 | 13-10-10 | 20 | 18 | 3" barrel, 18" drives |
| 2 | 36.5-38.0 | 7-6-5 | 11 | 18 | |
| 3 | 38.0-39.5 | 4-5-5 | 10 | 18 | |
| 4 | 39.5-41.0 | 4-6-8 | 14 | 18 | |
| 5 | 41.0-43.0 | 3-2-3-5 | 5 | 13.5 | 2" spilt spoon, 24" drives |
| 6 | 43.0-45.0 | 1-3-4-6 | 7 | 12 | used water to keep static head |
| 7 | 45.0-47.0 | 2-4-5-9 | 9 | 16 | |
| 8 | 47.0-49.0 | 6-13-15-17 | 28 | 20.5 | |
| 9 | 49.0-51.0 | 6-11-14-14 | 25 | 20 | |
| 10 | 51.0-53.0 | 4-7-12-15 | 19 | 24 | |

3" Spoon Data

| | | |
|-----------------------|--|--------|
| Site Location: | Plattsburgh, AFB | |
| Date: | 08/19/96 | |
| Personnel on site: | S.Kelley, M.Mitchell, M. Rodick, AJL, M. Meyer, D. Ostendorf, R. Suchan B. Charkhow, B. Glass, C. Francis | |
| Drillers & Drill Rig: | CTB - Steve Butrej, Chad | CME 75 |
| | 12BB | |
| Boring Information: | Samples continuous from 0.0' to 20.0' , augered with 3 1/4" augers to 20. | |
| Rods used: | NWJ | |
| SPT Protocol: | 3" Split Spoon sampler driven with a 140 lb. automatic hammer with a 30 Unlined split spoon with torque test. | |
| Torque Meas. Info.: | P-3500 strain indicator (UMA107640), Gage factor = 1.000 | |
| Location: | 6' West of 12AV | |

| Sample # | Depth (ft) | Blows/6" | N-value | Torque (ft-lb) | Recovery (in) |
|----------|------------|----------|---------|----------------|---------------|
| 1 | 0-1.5 | 4-12-8 | 20 | 108.2 | 17 |
| 2 | 1.5-3.0 | 2-2-2 | 4 | 59.8 | 20 |
| 3 | 3.0-4.5 | 2-1-2 | 3 | 50.0 | 15 |
| 4 | 4.5-6.0 | 2-5-8 | 13 | 62.1 | 12 |
| 5 | 6.0-7.5 | 5-7-12 | 19 | 216.8 | 14 |
| 6 | 7.5-9.0 | 6-9-11 | 20 | 275.5 | 18 |
| 7 | 9.0-10.5 | 8-14-16 | 30 | 347.9 | 19 |
| 8 | 10.5-12.0 | 9-16-22 | 38 | 455.7 | 18 |
| 9 | 12.0-13.5 | 15-27-29 | 56 | 676.2 | 19 |
| 10 | 13.5-15.0 | 11-20-24 | 44 | 509.2 | 20 |
| 11 | 15.0-16.5 | 11-15-16 | 31 | 475.7 | 18 |
| 12 | 16.5-18.0 | 12-15-17 | 32 | 424.8 | 20 |
| 13 | 18.0-19.5 | 9-11-11 | 22 | 318.5 | 19.5 |

| Solid 3" sampler | Sample # | Depth (ft) | Blows/6" | N-value | Recovery (in) |
|------------------|----------|------------|----------|---------|---------------|
| | 1 | 34.0-35.5 | 7-8-9 | 17 | 18 |
| | 2 | 35.5-37.0 | 3-9-7 | 16 | 17 |
| | 3 | 37.0-38.5 | 4-4-5 | 9 | 18 |
| | 4 | 38.5-40.0 | 3-5-6 | 11 | 20 |
| | 5 | 40.0-41.5 | 3-6-7 | 13 | 0 |
| | 6 | 40.0-42.0 | woh-2-4 | 2 | 12 |
| | 7 | 42.0-44.0 | 2-4-4-7 | 8 | 11 |
| | 8 | 44.0-46.0 | 3-4-4-7 | 8 | 15 |
| | 9 | 46.0-48.0 | 4-4-7-7 | 11 | 17 |

2" Spoon Data

| | |
|-----------------------|--|
| Site Location: | Plattsburgh, AFB |
| Date: | 08/20/96 |
| Personnel on site: | S.Kelley, M.Mitchell, M. Rodick, AJL, M. Meyer, D. Ostendorf, R. Suchana, B. Charkhow, B. Glass, C. Francis |
| Drillers & Drill Rig: | CTB - Steve Butrej, Chad CME 75 |
| | 12BF |
| Boring Information: | Samples continuous from 1.5' to 20.0' , augered with 3 1/4" augers to 20.0' - 35.0', soil samples 35.0' - 47. |
| Rods used: | NWJ |
| SPT Protocol: | 2" Split Spoon sampler driven with a 140 lb. safety hammer with a 30" drop height Unlined split spoon with torque test. |
| Torque Meas. Info.: | P-3500 strain indicator (UMA107640), Gage factor = 1.000 |
| Location: | 7' North of 12BE, 5 1/2' West 12AW |

| Sample # | Depth (ft) | Blows/6" | N-value | Torque (ft-lb) | Recovery (in) | notes |
|----------|------------|----------|---------|----------------|---------------|--------------------------------|
| 1 | 1.5-3.0 | 4-6-5 | 11 | 61.3 | 10 | Brown sand with cobbles |
| 2 | 3.0-4.5 | 5-3-5 | 8 | 12.4 | 8 | " |
| 3 | 4.5-6.0 | 4-6-6 | 12 | 64.2 | 12 | Fine to med. yellow sand |
| 4 | 6.0-7.5 | 4-5-6 | 11 | 83.6 | 14 | fine to med. yellowish orange |
| 5 | 7.5-9.0 | 5-8-11 | 19 | 106.6 | 14 | fine tan sand |
| 6 | 9.0-10.5 | 8-10-16 | 26 | 200.2 | 16 | " |
| 7 | 10.5-12.0 | 7-11-16 | 27 | 160.3 | 17 | fine tan with some yellow fine |
| 8 | 12.0-13.5 | 8-16-25 | 41 | 218.6 | 16 | " |
| 9 | 13.5-15.0 | 9-17-23 | 40 | 296.2 | 16 | " |
| 10 | 15.0-16.5 | 10-13-17 | 30 | 173.9 | 18 | " |
| 11 | 16.5-18.0 | 6-10-12 | 22 | 144.3 | 18 | " |
| 12 | 18.0-19.5 | 7-6-7 | 13 | 85.4 | 18 | small silt layer |

| Solid 3" sampler | Sample # | Depth (ft) | Blows/6" | N-value | Recovery (in) | notes |
|------------------|----------|------------|----------|---------|---------------|-------------------------------|
| | 1 | 35.0-36.5 | 8-16-14 | 30 | 18 | |
| | 2 | 36.5-38.0 | 6-8-10 | 18 | 18 | |
| | 3 | 38.0-39.5 | 4-8-11 | 19 | 18 | |
| | 4 | 39.5-41.5 | 4-5-11 | 16 | 6 | @ 40.0' started running water |
| | 5 | 39.5-41.5 | woh-6-7 | 6 | 22 | switched to 2"ss |
| | 6 | 41.5-43.5 | 1-2-5-7 | 7 | 18 | |
| | 7 | 43.5-45.5 | 3-6-8-7 | 14 | 19 | |
| | 8 | 45.5-47.5 | 3-5-5-8 | 10 | 12 | |

4" Stainless Steel Solid Core Data

| | | | | |
|-----------------------|---|-----------------------------|---------------|-------|
| Site Location: | Plattsburgh, AFB | | | |
| Date: | 08/21/96 | | | |
| Personnel on site: | S.Kelley, M.Mitchell, M. Rodick, A.J.L, M. Meyer, R. Suchana, B. Charkhow, B. Glass | | | |
| Drillers & Drill Rig: | CTB - Steve Butrej, Chad | | CME 75 | |
| | 12BG | | | |
| Boring Information: | Augered with 4 1/2" augers, samples from root zone, capillary fringe, and contamination source | | | |
| Rods used: | NWJ | | | |
| SPT Protocol: | 4" stainless steel solid core sampler driven with a 140 lb. automatic hammer with a 30" drop height | | | |
| Location: | n/a | | | |
| | | | | |
| Sample # | Depth (ft) | Blows/6" | Recovery (in) | notes |
| 1 | 0.0-3.0 | 7-10-8-4-4-6 | 27.5 | |
| 2 | 36.0-39.0 | 5-17-21-25-28-21 | 27.5 | |
| 3 | 39.0-42.0 | 6-9-10-15-16-17 | 36 | |

Vapor Probe Data

| | | | |
|-----------------------|---|----------|-------|
| Site Location: | Plattsburgh, AFB | | |
| Date: | 08/21/96 | | |
| Personnel on site: | S.Kelley, M.Mitchell, M. Rodick, AJL, M. Meyer, R. Suchana, B. Charkhow, B. Glass | | |
| Drillers & Drill Rig: | CTB - Steve Butrej, Chad | CME 75 | |
| | 12BH | | |
| Boring Information: | Augered with 3 1/4" augers to 0.0' - 30.0', soil gas sampling 30.0' - 36.0' | | |
| Rods used: | NWJ | | |
| SPT Protocol: | Vapor probe sampler driven with a 140 lb. automatic hammer with a 30" drop height Exposed flush mounted sintered steel filter soil gas probe | | |
| Location: | 3' north 12AP, 3' south 12BA, 5' east of fence | | |
| | | | |
| Sample # | Depth (ft) | Blows/6" | notes |
| 1 | 30.0-30.5 | 6 | |
| 2 | 30.5-31.0 | 13 | |
| 3 | 31.0-31.5 | 14 | |
| 4 | 31.5-32.0 | 13 | |
| 5 | 32.0-32.5 | 22 | |
| 6 | 32.5-33.0 | 19 | |
| 7 | 33.0-33.5 | 15 | |
| 8 | 33.5-34.0 | 10 | |
| 9 | 34.0-34.5 | 8 | |
| 10 | 34.5-35.0 | 5 | |
| 11 | 35.0-35.5 | 5 | |
| 12 | 35.5-36.0 | 4 | |

2" Spoon Data

| | |
|-----------------------|---|
| Site Location: | Plattsburgh, AFB |
| Date: | 08/21/96 |
| Personnel on site: | S.Kelley, M.Mitchell, M. Rodick, AJL, M. Meyer, R. Suchana, B. Charkhow, B. Glass |
| Drillers & Drill Rig: | CTB - Steve Butrej, Chad CME 75 |
| | 12BI |
| Boring Information: | Samples every 5' from 5' to 35' , augered with 3 1/4" augers to 37.0', soil samples 37.0' - 47.5' |
| Rods used: | NWJ |
| SPT Protocol: | 2" Split Spoon sample driven with an automatic 140 lb. hammer with a 30" drop height Unlined split spoon with torque test. |
| Torque Meas. Info.: | P-3500 strain indicator (UMA107640), Gage factor = 1.000 |
| Location: | 9' East of fence, 2' North of 12AH |

| Sample # | Depth (ft) | Blows/6" | N-value | Torque (ft-lb) | Recovery (in) | notes |
|----------|------------|-------------|---------|----------------|---------------|-------------------------------------|
| 1 | 5.0-7.0 | 4-5-4-6 | 9 | 84.2 | 12 | hit sand layer at bot. of spoon |
| 2 | 10.0-12.0 | 9-9-11-13 | 20 | 159.4 | 12 | tan fine-med. sand |
| 3 | 15.0-17.0 | 15-24-20-21 | 44 | 159.4 | 12.5 | " |
| 4 | 20.0-22.0 | 3-7-6-8 | 13 | 130.1 | 22 | fine tan sand |
| 5 | 25.0-27.0 | 4-8-9-10 | 17 | 193.8 | 22 | fine tan sand with 2" layer of silt |
| 6 | 30.0-32.0 | 3-7-16-24 | 23 | 324.7 | 20 | fine tan sand |
| 7 | 35.0-37.0 | 4-5-5-8 | 10 | 92.9 | 17 | fine to med moist tan sand |

| Solid 3" sampler | Sample # | Depth (ft) | Blows/6" | N-value | Recovery (in) | notes |
|------------------|----------|------------|----------|---------|---------------|-------------------------------|
| | 1 | 37.0-38.5 | 5-7-8 | 15 | 18 | |
| | 2 | 38.5-40.0 | 3-4-6 | 10 | 16 | |
| | 3 | 40.0-41.5 | 3-4-4 | 8 | 9.5 | @ 40.0' started running water |
| | 4 | 41.5-43.5 | 1-2-3-4 | 5 | 14 | switched to 2"ss |
| | 5 | 43.5-45.5 | 2-3-5-6 | 8 | 14 | |
| | 6 | 45.5-47.5 | 1-3-6-7 | 9 | 16 | |

Vapor and Resistivity Probe Data

| | | | |
|-----------------------|---|--------|--|
| Site Location: | Plattsburgh AFB | | |
| Date: | 08/21/96 | | |
| Personnel on site: | S.Kelley, M.Mitchell, M. Rodick, AJL, M. Meyer, R. Suchana, B. Charkhow, B. Glass | | |
| Drillers & Drill Rig: | CTB - Steve Butrej, Chad | CME 75 | |
| | 12BJ | | |
| Boring Information: | Augered with 3 1/4" augers down to 30.0', soil gas sampling 30.0' - 47.5' | | |
| Rods used: | NWJ | | |
| SPT Protocol: | Vapor probe sampler driven with a 140 lb. automatic hammer with a 30" drop height Exposed flush mounted sintered steel filter soil gas probe | | |
| Location: | 13.5' east of fence and 1' north from 12BA | | |

| Sample # | Depth (ft) | Blows/6" | notes |
|----------|------------|----------|----------------------|
| 1 | 30.0-30.5 | 8 | |
| 2 | 30.5-31.0 | 18 | |
| 3 | 31.0-31.5 | 21 | |
| 4 | 31.5-32.0 | 28 | |
| 5 | 32.0-32.5 | 29 | |
| 6 | 32.5-33.0 | 23 | |
| 7 | 33.0-33.5 | 22 | |
| 8 | 33.5-34.0 | 18 | |
| 9 | 34.0-34.5 | 11 | |
| 10 | 34.5-35.0 | 9 | |
| 11 | 35.0-35.5 | 7 | |
| 12 | 35.5-36.0 | 8 | Hit capillary fringe |
| 13 | 36.0-36.5 | 8 | |
| 14 | 36.5-37.0 | 8 | |
| 15 | 37.0-37.5 | 6 | |
| 16 | 37.5-38.0 | 8 | |
| 17 | 38.0-38.5 | 7 | |
| 18 | 38.5-39.0 | 6 | |
| 19 | 39.0-39.5 | 7 | |
| 20 | 39.5-40.0 | 7 | |
| 21 | 40.0-40.5 | 7 | |
| 22 | 40.5-41.0 | 7 | |
| 23 | 41.0-41.5 | 7 | |
| 24 | 41.5-42.0 | 8 | |
| 25 | 42.0-42.5 | 6 | |
| 26 | 42.5-43.0 | 8 | |
| 27 | 43.0-43.5 | 8 | |
| 28 | 43.5-44.0 | 8 | |
| 29 | 44.0-44.5 | 8 | |
| 30 | 44.5-45.0 | 11 | |
| 31 | 45.0-45.5 | 12 | |
| 32 | 45.5-46.0 | 13 | |
| 33 | 46.0-46.5 | 14 | |
| 34 | 46.5-47.0 | 16 | |
| 35 | 47.0-47.5 | 15 | |

Vapor Probe Data

| | | | |
|-----------------------|---|----------|-------------------------------------|
| Site Location: | Plattsburgh, AFB | | |
| Date: | 08/22/96 | | |
| Personnel on site: | S.Kelley, M.Mitchell, M. Rodick, M. Meyer, R. Suchana, B. Glass | | |
| Drillers & Drill Rig: | CTB - Steve Butrej, Chad | CME 75 | |
| | 12BK | | |
| Boring Information: | Augered with 3 1/4" augers to 0.0' - 30.0', soil gas sampling 30.0' - 37.0' | | |
| Rods used: | NWJ | | |
| SPT Protocol: | Vapor probe sampler driven with a 140 lb. automatic hammer with a 30" drop height Exposed flush mounted sintered steel filter soil gas probe | | |
| Location: | 6' west of 12AK and 4.5' south of dog house | | |
| | | | |
| Sample # | Depth (ft) | Blows/6" | notes |
| 1 | 30.0-30.5 | 8/8" | vac'm @ 5"Hg |
| 2 | 30.5-31.0 | 11 | Blank (TLV=100, O2=20.5, CO2=0.046) |
| 3 | 31.0-31.5 | 10 | |
| 4 | 31.5-32.0 | N/A | |
| 5 | 32.0-32.5 | 11 | vac'm @ 10"Hg |
| 6 | 32.5-33.0 | 13 | |
| 7 | 33.0-33.5 | 15 | TLV=240, O2=16.9, CO2=1.3 |
| 8 | 33.5-34.0 | 19 | |
| 9 | 34.0-34.5 | 17 | |
| 10 | 34.5-35.0 | 17 | |
| 11 | 35.0-35.5 | 15 | |
| 12 | 35.5-36.0 | 14 | vac'm @ 11"Hg |
| 13 | 36.0-36.5 | 14 | TLV=540, O2=16.9, CO2=1.3 |
| 14 | 36.5-37.0 | 13 | TLV=700, O2=16.9, CO2=1.3 |

Vapor and Resistivity Probe Data

| | |
|-----------------------|---|
| Site Location: | Plattsburgh, AFB |
| Date: | 08/22/96 |
| Personnel on site: | S.Kelley, M.Mitchell, M. Rodi |
| Drillers & Drill Rig: | CTB - Steve Butrej, Chad |
| | 12BL |
| Boring Information: | Augered with 3 1/4" augers |
| Rods used: | NWJ |
| SPT Protocol: | Vapor probe sampler driven Exposed flush mounted sinte |
| Location: | 4.5' south of 12 BE, 7.5' east |

| Sample # | Depth (ft) | Blows/6" |
|----------|------------|----------|
| 1 | 30.0-30.5 | 4/8" |
| 2 | 30.5-31.0 | 8 |
| 3 | 31.0-31.5 | 7 |
| 4 | 31.5-32.0 | 10 |
| 5 | 32.0-32.5 | 13 |
| 6 | 32.5-33.0 | 14 |
| 7 | 33.0-33.5 | 12 |
| 8 | 33.5-34.0 | 12 |
| 9 | 34.0-34.5 | 10 |
| 10 | 34.5-35.0 | 9 |
| 11 | 35.0-35.5 | 7 |
| 12 | 35.5-36.0 | 6 |
| 13 | 36.0-36.5 | 4 |
| 14 | 36.5-37.0 | 4 |
| 15 | 37.0-37.5 | 2 |
| 16 | 37.5-38.0 | 2 |
| 17 | 38.0-38.5 | 2 |
| 18 | 38.5-39.0 | 1 |
| 19 | 39.0-39.5 | 1 |
| 20 | 39.5-40.0 | 2 |
| 21 | 40.0-40.5 | 1 |
| 22 | 40.5-41.0 | 1 |
| 23 | 41.0-41.5 | 2 |
| 24 | 41.5-42.0 | 2 |
| 25 | 42.0-42.5 | 2 |
| 26 | 42.5-43.0 | 3 |

Vapor Probe Data

| | |
|-----------------------|--|
| Site Location: | Plattsburgh, AFB |
| Date: | 08/22/96 |
| Personnel on site: | S.Kelley, M.Mitchell, M. Ro |
| Drillers & Drill Rig: | CTB - Steve Butrej, Chad |
| | 12BM |
| Boring Information: | Augered with 3 1/4" augers |
| Rods used: | NWJ |
| SPT Protocol: | Vapor probe sampler driven Exposed flush mounted sint |
| Location: | 9' west of center of west sid |

| Sample # | Depth (ft) | Blows/6" |
|----------|------------|----------|
| 1 | 30.0-30.5 | 6/8" |
| 2 | 30.5-31.0 | 9 |
| 3 | 31.0-31.5 | 13 |
| 4 | 31.5-32.0 | 11 |
| 5 | 32.0-32.5 | 11 |
| 6 | 32.5-33.0 | 16 |
| 7 | 33.0-33.5 | 18 |
| 8 | 33.5-34.0 | 17 |
| 9 | 34.0-34.5 | 17 |
| 10 | 34.5-35.0 | 14 |
| 11 | 35.0-35.5 | 10 |
| 12 | 35.5-36.0 | 10 |
| 13 | 36.0-36.5 | 9 |
| 14 | 36.5-37.0 | 10 |

Vapor Probe Data

| | | | |
|-----------------------|---|----------|--------------------------------------|
| Site Location: | Plattsburgh, AFB | | |
| Date: | 08/22/96 | | |
| Personnel on site: | S.Kelley, M.Mitchell, M. Rodick, M. Meyer, R. Suchana, B. Glass | | |
| Drillers & Drill Rig: | CTB - Steve Butrej, Chad | CME 75 | |
| | 12BN | | |
| Boring Information: | Augered with 3 1/4" augers down to 30.0', soil gas sampling 30.5' - 36.5' | | |
| Rods used: | NWJ | | |
| SPT Protocol: | Vapor probe sampler driven with a 140 lb. automatic hammer with a 30" drop height Exposed flush mounted sintered steel filter soil gas probe | | |
| Location: | 21.5' north NW corner side of dog house, 14.5' west of fence | | |
| | | | |
| Sample # | Depth (ft) | Blows/6" | notes |
| 1 | 30.0-30.5 | 6/8" | vac'm @ 10"Hg |
| 2 | 30.5-31.0 | 13 | vac'm @ 11"Hg |
| 3 | 31.0-31.5 | 16 | vac'm @ 11.5"Hg |
| 4 | 31.5-32.0 | 21 | vac'm @ 13" Hg |
| 5 | 32.0-32.5 | 21 | vac'm @ 13" Hg |
| 6 | 32.5-33.0 | 28 | vac'm @ 13" Hg |
| 7 | 33.0-33.5 | 13 | vac'm @ 13" Hg |
| 8 | 33.5-34.0 | 14 | vac'm @ 13.5" Hg |
| 9 | 34.0-34.5 | 12 | vac'm @ 13.5" Hg |
| 10 | 34.5-35.0 | 11 | vac'm @ 13.5" Hg |
| 11 | 35.0-35.5 | 8 | vac'm @ 14" Hg |
| 12 | 35.5-36.0 | 9 | vac'm @ 12" Hg |
| 13 | 36.0-36.5 | 9 | Hit capillary fringe Vac'm >23.0" Hg |

2" Split Spoon Data

| | |
|---------------------|----------------------------------|
| Site Location: | Plattsburgh AFB |
| Date: | 08/22/96 |
| Personnel on site: | S.Kelley, M.Mitchell, M. Rodic |
| Drillers: | CTB - Steve, Chad |
| 12BO | |
| Boring Information: | Augered down to 30.0', soil g |
| Rods used: | NWJ |
| SPT Protocol: | 2" Split Spoon sampler jacked |
| Torque Meas. Info.: | P-3500 strain indicator (UMA1 |
| Thrust Meas. Info.: | P-3500 strain indicator (UMA1 |
| Location: | 4' east of fence, 8, north of 12 |

| Sample # | Depth (ft) | Thrust (lbf) |
|----------|------------|--------------|
| 1 | 0-1.5 | |
| 2 | 1.5-3.0 | |
| 3 | 3.0-4.5 | |
| 4 | 4.5-6.0 | |
| 5 | 6.5-8.0 | |
| 6 | 8.0-9.5 | |
| 7 | 9.5-11.0 | |
| 8 | 11.0-12.5 | |
| 9 | 12.5-14.0 | |
| 10 | 14.0-15.5 | |
| 11 | 15.5-17.0 | |
| 12 | 17.0-18.5 | |
| 13 | 18.5-20.0 | |

2" Spoon Data

| | |
|--------------------|--|
| Site Location: | Plattsburgh AFB |
| Date: | 10/12/95 |
| Personnel on site: | S.Kelley, C. Riccardi, T. Mitchell, P.Cheever R. Suchana, E. Hinlein, M. McGrath, P. Reyes, R. Miknis |
| Drillers: | CTB - Steve, Johnny |

SPK1

| | |
|---------------------|---|
| Boring Information: | Continuous sampling from surface |
| Rods used: | NWJ |
| SPT Protocol: | Automatic 140 lb. hammer with a 30" drop height |
| Location: | 15' Southeast from 12AA |

| Core # | Depth (ft) | Blows/6" | N-value | Recovery | notes |
|--------|------------|----------|---------|----------|------------------------------|
| 1 | 0-1.5 | 4-3-1 | 4 | 2 | |
| 2 | 1.5-3.0 | WOH | 2 | 0 | |
| 3 | 3.0-4.5 | 2-3-6 | 9 | 15 | |
| 4 | 4.5-6.0 | 5-5-6 | 11 | 14 | |
| 5 | 6.0-7.5 | 2-4-3 | 7 | 15 | |
| 6 | 7.5-9.0 | 4-6-9 | 15 | 14 | |
| 7 | 9.0-10.5 | 6-9-10 | 19 | 15 | |
| 8 | 10.5-12.0 | 7-11-12 | 23 | 17 | |
| 9 | 12.0-13.5 | 6-11-18 | 29 | 17 | |
| 10 | 13.5-15.0 | 13-20-21 | 41 | 17 | |
| 11 | 15.0-16.5 | 5-9-14 | 23 | 14 | |
| 12 | 16.5-18.0 | 6-12-14 | 26 | 16 | |
| 13 | 18.0-19.5 | 7-9-10 | 19 | 16 | |
| 14 | 19.5-21.0 | 4-6-6 | 12 | 17 | |
| 15 | 21.0-22.5 | 5-7-8 | 15 | 17 | |
| 16 | 22.5-24.0 | 5-6-7 | 13 | 16 | |
| 17 | 24.0-25.5 | 6-7-8 | 15 | 16 | |
| 18 | 25.5-27.0 | 4-5-7 | 12 | 17 | |
| 19 | 27.0-28.5 | 5-7-11 | 18 | 17 | |
| 20 | 28.5-30.0 | 9-17-15 | 32 | 19 | |
| 21 | 30.0-31.5 | 6-8-11 | 19 | 17 | |
| 22 | 31.5-33.0 | 8-15-18 | 33 | 17 | |
| 23 | 33.0-34.5 | 12-16-16 | 32 | 19 | |
| 24 | 34.5-36.0 | 8-11-13 | 24 | 18 | |
| 25 | 36.0-37.5 | 7-10-15 | 25 | 19 | |
| 26 | 37.5-39.0 | 4-6-8 | 14 | 18 | Water used to keep hole open |
| 27 | 39.0-40.5 | 3-7-11 | 18 | 16 | |
| 28 | 40.5-42.0 | 1-8-12 | 20 | 15 | |
| 29 | 42.0-43.5 | 5-9-10 | 19 | 13 | |
| 30 | 43.5-45.0 | 4-5-7 | 12 | 14 | |

End of Boring

2" Spoon Data

| | |
|--------------------|---|
| Site Location: | Plattsburgh AFB |
| Date: | 12/2/95 |
| Personnel on site: | S.Kelley, Dr. Lutenegeger, Dr. DeGroot, T. Mitchell, G. Costa R. Mikinis, R. Suchana, P.Reyes, B.Glass, Chris, B. Charkhow P. Tehrany, D. Ostendorf, E. Hinlein |
| Drillers: | CTB - Steve and Johnny |

SPK2

| | |
|---------------------|---|
| Boring Information: | Augured with 3 1/4" augers and sampled continuous from surface to 40.5' |
| Rods used: | NWJ |
| SPT Protocol: | Automatic 140 lb. hammer with a 30" height |
| Location: | 24' northwest of 12AA |

| Core # | Depth (ft) | Blows/6" | N-value | Recovery | notes |
|--------|------------|-----------|---------|----------|------------------------------|
| 1 | 0-1.5 | 4-3-4 | 7 | 18 | |
| 2 | 1.5-3.0 | 2-1-2 | 3 | 17 | |
| 3 | 3.0-4.5 | 1-1-1 | 2 | 18 | |
| 4 | 4.5-6.0 | WOH-1-1 | 2 | 2 | |
| 5 | 6.0-7.5 | WOH-WOH-1 | 2 | 2 | |
| 6 | 7.5-9.0 | 2-2-4 | 6 | 10 | |
| 7 | 9.0-10.5 | 5-4-5 | 9 | 18 | |
| 8 | 10.5-12.0 | 5-5-6 | 11 | 18 | |
| 9 | 12.0-13.5 | 6-7-9 | 16 | 18 | |
| 10 | 13.5-15.0 | 6-8-10 | 18 | 18 | |
| 11 | 15.0-16.5 | 6-8-10 | 18 | 18 | |
| 12 | 16.5-18.0 | 7-8-9 | 17 | 18 | |
| 13 | 18.0-19.5 | 5-4-5 | 9 | 18 | |
| 14 | 19.5-21.0 | 3-3-5 | 8 | 18 | |
| 15 | 21.0-22.5 | 7-6-7 | 13 | 18 | |
| 16 | 22.5-24.0 | 4-5-6 | 11 | 18 | |
| 17 | 24.0-25.5 | 6-6-7 | 13 | 18 | |
| 18 | 25.5-27.0 | 5-6-10 | 16 | 19 | |
| 19 | 27.0-28.5 | 9-12-20 | 32 | 19 | |
| 20 | 28.5-30.0 | 15-17-19 | 36 | 19 | |
| 21 | 30.0-31.5 | 9-8-9 | 17 | 17 | |
| 22 | 31.5-33.0 | 7-12-14 | 26 | 17 | |
| 23 | 33.0-34.5 | 7-11-13 | 24 | 16 | |
| 24 | 34.5-36.0 | 8-11-11 | 22 | 18 | |
| 25 | 36.0-37.5 | 5-6-8 | 14 | 18 | |
| 26 | 37.5-39.0 | 3-5-7 | 12 | 17 | Water used to keep hole open |
| 27 | 39.0-40.5 | 5-6-7 | 13 | 20 | |

End of Boring

3" Spoon Data

| | | | | | |
|---------------------|--|----------|---------|----------|----------------------|
| Site Location: | Plattsburgh AFB | | | | |
| Date: | 11/30/95 | | | | |
| Personnel on site: | S.Kelley, Dr. Lutenegger, Dr. DeGroot, T. Mitchell, G. Costa R. Mikinis, R. Suchana, P.Reyes, B.Glass, Chris, B. Charkhow P. Tehrany, D. Ostendorf, E. Hinlein | | | | |
| Drillers: | CTB - Steve and Johnny | | | | |
| | | Vent 1 | | | |
| Boring Information: | Augered to 35' (with 6 1/4" augers) and sample continuous from 35' to 42.5' | | | | |
| Rods used: | NWJ | | | | |
| SPT Protocol: | Automatic 140 lb. hammer with a 30" height | | | | |
| Location: | 2.5' north of 12AA | | | | |
| | | | | | |
| Core # | Depth (ft) | Blows/6" | N-value | Recovery | notes |
| 1 | 35.0-36.5 | 4-10-10 | 20 | 18 | |
| 2 | 36.5-38.0 | 6-10-10 | 20 | 18 | dark brown sand |
| 3 | 38.0-39.5 | 4-4-7 | 11 | 18 | water table at 39.5' |
| 4 | 39.5-41.0 | 3-3-5 | 8 | 17 | grey sand with odor |
| 5 | 41.0-42.5 | 1-3-5 | 8 | 18 | |

3" Spoon Data

| | | | | | |
|---------------------|--|-------------|---------|----------|----------------------|
| Site Location: | Plattsburgh AFB | | | | |
| Date: | 11/30/95 | | | | |
| Personnel on site: | S.Kelley, Dr. Lutenegger, Dr. DeGroot, T. Mitchell, G. Costa R. Mikinis, R. Suchana, P.Reyes, B.Glass, Chris, B. Charkhow P. Tehrany, D. Ostendorf, E. Hinlein | | | | |
| Drillers: | CTB - Steve and Johnny | | | | |
| | | Vent 2 | | | |
| Boring Information: | Augered to 35' (with 6 1/4" augers) and sample continuous from 35' to 43.0' | | | | |
| Rods used: | NWJ | | | | |
| SPT Protocol: | Automatic 140 lb. hammer with a 30" height | | | | |
| Location: | 2.5'south of 12AA | | | | |
| | | | | | |
| Core # | Depth (ft) | Blows/6" | N-value | Recovery | notes |
| 1 | 35.0-36.5 | 2-5-5 | 10 | 18 | |
| 2 | 36.5-38.0 | 1-4-5 | 9 | 17 | dark brown sand |
| 3 | 38.0-39.5 | 3-3-4 | 7 | 18 | water table at 39.5' |
| 4 | 39.5-41.0 | 3-4-4 | 8 | 18 | grey sand with odor |
| 5 | 41.0-43.0 | 2-3-4-5 | 7 | 0 | SCSS |
| 6 | 41.0-43.0 | OH-WOH-WOH- | 2 | 24 | 2" split spoon |

3" Spoon Data

| | | | | | |
|---------------------|--|-------------|-----------------|----------|----------------------|
| Site Location: | Plattsburgh AFB | | | | |
| Date: | 12/1/95 | | | | |
| Personnel on site: | S.Kelley, Dr. Lutenegger, Dr. DeGroot, T. Mitchell, G. Costa R. Mikinis, R. Suchana, P.Reyes, B.Glass, Chris, B. Charkhow P. Tehrany, D. Ostendorf, E. Hinlein | | | | |
| Drillers: | CTB - Steve and Johnny | | | | |
| | | | Sparge 1 | | |
| Boring Information: | Augered to 35' (with 6 1/4" augers) and sample continuous from 35' to 49.5' | | | | |
| Rods used: | NWJ | | | | |
| SPT Protocol: | Automatic 140 lb. hammer with a 30" height | | | | |
| Location: | 2.5' west of 12AA | | | | |
| | | | | | |
| Core # | Depth (ft) | Blows/6" | N-value | Recovery | notes |
| 1 | 35.0-36.5 | 7-8-7 | 15 | 18 | |
| 2 | 36.5-38.0 | 5-5-6 | 11 | 18 | |
| 3 | 38.0-39.5 | 4-5-5 | 10 | 18 | water table at 39.5' |
| 4 | 39.5-41.0 | 4-4-4 | 8 | 18 | |
| 5 | 41.0-42.5 | 2-2-4 | 6 | 16 | |
| 6 | 42.5-44 | 8-6-8 | 14 | 11 | |
| 7 | 44.0-45.5 | 4-4-7 | 11 | 9.5 | |
| 8 | 45.5-47.0 | 5-8-9 | 17 | 10.5 | |
| 9 | 47.0-49.5 | 11-16-13-13 | 29 | 8/24 | 2" split spoon |

APPENDIX II TUBING CLUSTER DETAILS

Construction Details For Borehole/Soil Gas Cluster

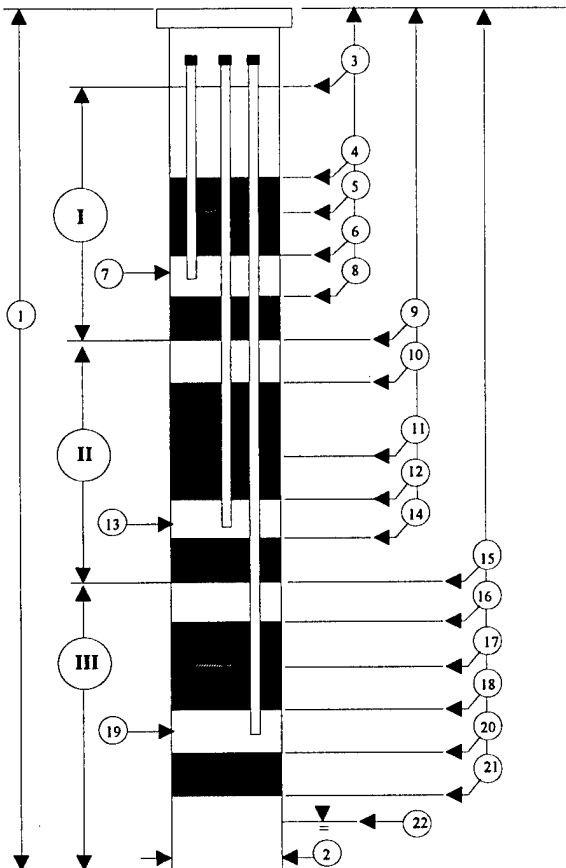
12AA

Data Entered by: ESH

Date Installed: 10/9/95

Date Entered: 2/18/97

Manhole Elevation: 256.26'



| | | |
|-----|------------------------------------|---------|
| 1. | Depth of Borehole | 51.5 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | 15.0 |
| 5. | Depth to Top of Upper Seal I | 22.5 |
| 6. | Depth to Top of Sand I | 23.5 |
| 7. | Depth of Cluster Point I | 24.0 |
| | Depth (ft MSL) | 232.26' |
| 8. | Depth to Top of Lower Seal I | 27.0 |
| 9. | Depth to Top of Fill II | N/A |
| 10. | Depth to Top of Slurry II | 27.5 |
| 11. | Depth to Top of Upper Seal II | 37.5 |
| 12. | Depth to Top of Sand II | 38.5 |
| 13. | Depth of Cluster Point II | 39.0 |
| | Depth (ft MSL) | 217.26' |
| 14. | Depth to Top of Lower Seal II | N/A |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | 39.5 |
| 18. | Depth to Top of Sand III | 44 |
| 19. | Depth of Cluster Point III | 45 |
| | Depth (ft MSL) | 211.26' |
| 20. | Depth to Top of Lower Seal III | N/A |
| | NOTE: CAVED IN FROM 29.0' TO 31.0' | |
| 21. | Depth to Top Remaining Fill | 47.5 |
| 22. | Depth to Water Table | 40.0 |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point

- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications

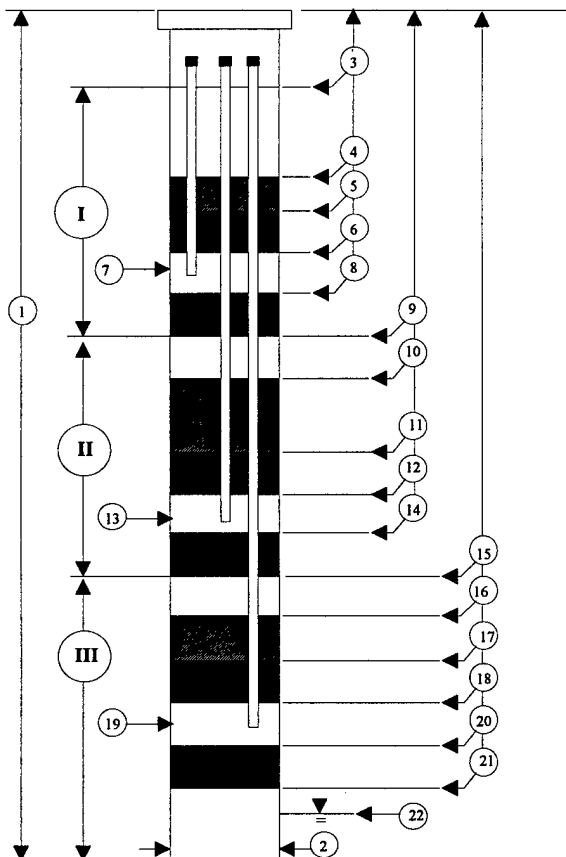
- 8" Cast iron manhole w/ galvanized steel, 8" diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

12AB

Data Entered by: ESH
Date Entered: 2/18/97

Date Installed: 10/10/95
Manhole Elevation: 256.33'



| | | |
|-----|--------------------------------|---------|
| 1. | Depth of Borehole | 51.5 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 1.0 |
| 4. | Depth to Top of Slurry I | N/A |
| 5. | Depth to Top of Upper Seal I | 2.0 |
| 6. | Depth to Top of Sand I | 3.0 |
| 7. | Depth of Cluster Point I | 3.5 |
| | Depth (ft MSL) | 241.33' |
| 8. | Depth to Top of Lower Seal I | 4.0 |
| 9. | Depth to Top of Fill II | 6.0 |
| 10. | Depth to Top of Slurry II | 8.6 |
| 11. | Depth to Top of Upper Seal II | 14.4 |
| 12. | Depth to Top of Sand II | 15.4 |
| 13. | Depth of Cluster Point II | 15.8 |
| | Depth (ft MSL) | 253.33' |
| 14. | Depth to Top of Lower Seal II | 16.4 |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | N/A |
| 18. | Depth to Top of Sand III | N/A |
| 19. | Depth of Cluster Point III | N/A |
| | Depth (ft MSL) | N/A |
| 20. | Depth to Top of Lower Seal III | N/A |
| 21. | Depth to Top Remaining Fill | 18.6 |
| 22. | Depth to Water Table | 40.0 |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.

- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications

- 8" Cast iron manhole w/ galvanized steel, 8" diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

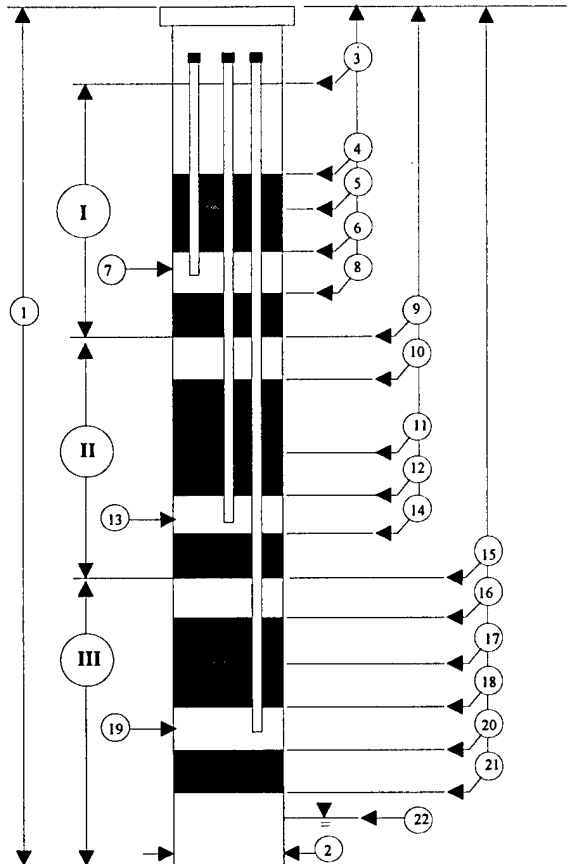
12AC

Data Entered by: ESH

Date Installed: 10/10/95

Date Entered: 2/18/97





Manhole Elevation: 256.50'



| | | |
|-----|--------------------------------|---------|
| 1. | Depth of Borehole | 19.5 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | 4.0 |
| 5. | Depth to Top of Upper Seal I | 5.0 |
| 6. | Depth to Top of Sand I | 6.0 |
| 7. | Depth of Cluster Point I | 6.4 |
| | Depth (ft MSL) | 238.50' |
| 8. | Depth to Top of Lower Seal I | 7.2 |
| 9. | Depth to Top of Fill II | N/A |
| 10. | Depth to Top of Slurry II | 9.2 |
| 11. | Depth to Top of Upper Seal II | 17.1 |
| 12. | Depth to Top of Sand II | 18.2 |
| 13. | Depth of Cluster Point II | 18.6 |
| | Depth (ft MSL) | 250.50' |
| 14. | Depth to Top of Lower Seal II | 19.2 |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | N/A |
| 18. | Depth to Top of Sand III | N/A |
| 19. | Depth of Cluster Point III | N/A |
| | Depth (ft MSL) | N/A |
| 20. | Depth to Top of Lower Seal III | N/A |
| 21. | Depth to Top Remaining Fill | N/A |
| 22. | Depth to Water Table | N/A |

All Dimensions in feet unless otherwise noted

Materials Legend

-  — Fill: Clean Native Fill
-  — Seal: Bentonite Pellets
-  — Sand: Pool sand
-  — Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.



- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications



- 8" Cast iron manhole
- w/ galvanized steel, 8" diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

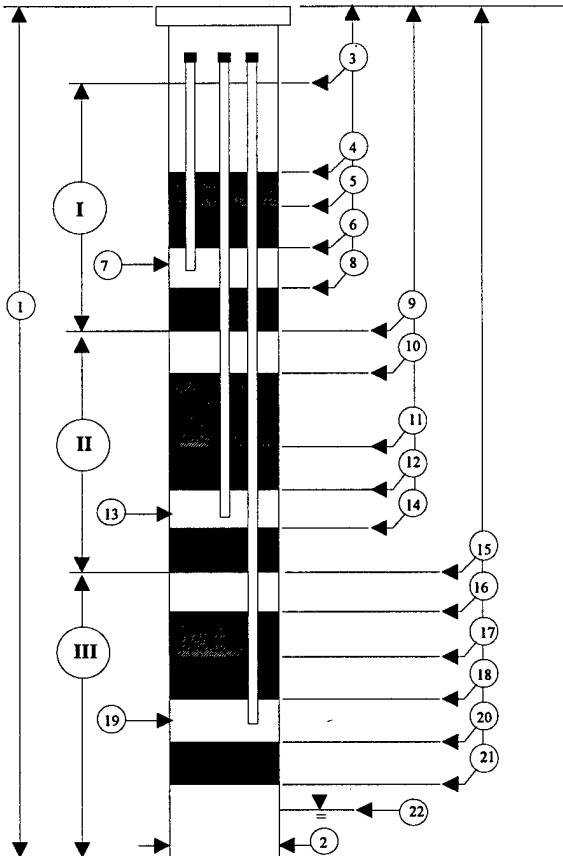
12AD

Data Entered by: ESH

Date Installed: 10/10/95

Date Entered: 2/18/97

Manhole Elevation: 256.34'



| | | |
|-----|--------------------------------|---------|
| 1. | Depth of Borehole | 48.0 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | 10.0 |
| 5. | Depth to Top of Upper Seal I | 11.1 |
| 6. | Depth to Top of Sand I | 12.0 |
| 7. | Depth of Cluster Point I | 12.5 |
| | Depth (ft MSL) | 232.34' |
| 8. | Depth to Top of Lower Seal I | 12.8 |
| 9. | Depth to Top of Fill II | 15.0 |
| 10. | Depth to Top of Slurry II | 18.6 |
| 11. | Depth to Top of Upper Seal II | 23.0 |
| 12. | Depth to Top of Sand II | 24.0 |
| 13. | Depth of Cluster Point II | 24.4 |
| | Depth (ft MSL) | 244.34' |
| 14. | Depth to Top of Lower Seal II | 24.8 |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | N/A |
| 18. | Depth to Top of Sand III | N/A |
| 19. | Depth of Cluster Point III | N/A |
| | Depth (ft MSL) | N/A |
| 20. | Depth to Top of Lower Seal III | N/A |
| 21. | Depth to Top Remaining Fill | 27.0 |
| 22. | Depth to Water Table | 40.0 |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.

- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications

- 8" Cast iron manhole w/ galvanized steel, 8" diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

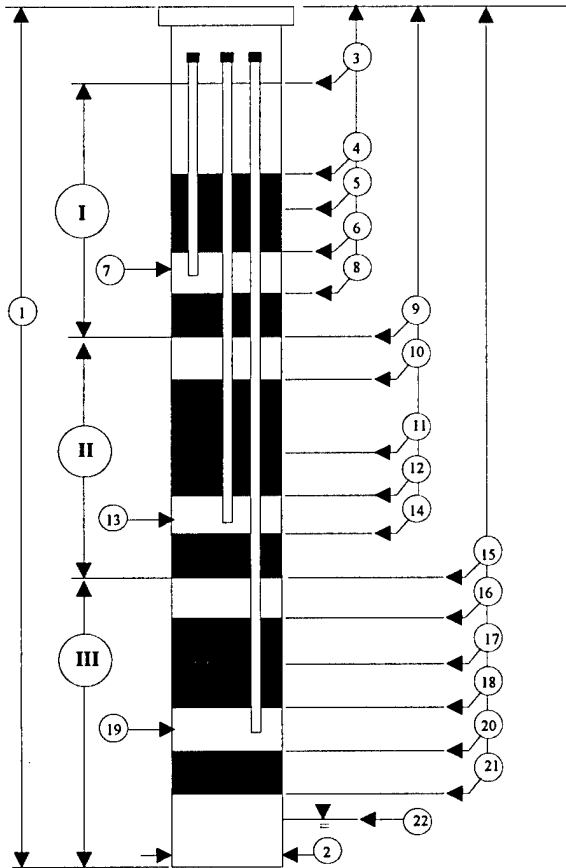
12AE

Data Entered by: ESH

Date Installed: 10/10/95

Date Entered: 2/18/97

Manhole Elevation: 256.70'



| | | |
|-----|--------------------------------|---------|
| 1. | Depth of Borehole | 19.0 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | 3.2 |
| 5. | Depth to Top of Upper Seal I | 5.2 |
| 6. | Depth to Top of Sand I | 6.4 |
| 7. | Depth of Cluster Point I | 7.0 |
| | Depth (ft MSL) | 239.20' |
| 8. | Depth to Top of Lower Seal I | 7.4 |
| 9. | Depth to Top of Fill II | 9.5 |
| 10. | Depth to Top of Slurry II | 11.2 |
| 11. | Depth to Top of Upper Seal II | 17.0 |
| 12. | Depth to Top of Sand II | 18.6 |
| 13. | Depth of Cluster Point II | 19.2 |
| | Depth (ft MSL) | 250.70' |
| 14. | Depth to Top of Lower Seal II | 19.8 |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | N/A |
| 18. | Depth to Top of Sand III | N/A |
| 19. | Depth of Cluster Point III | N/A |
| | Depth (ft MSL) | N/A |
| 20. | Depth to Top of Lower Seal III | N/A |
| 21. | Depth to Top Remaining Fill | N/A |
| 22. | Depth to Water Table | N/A |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.

- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications

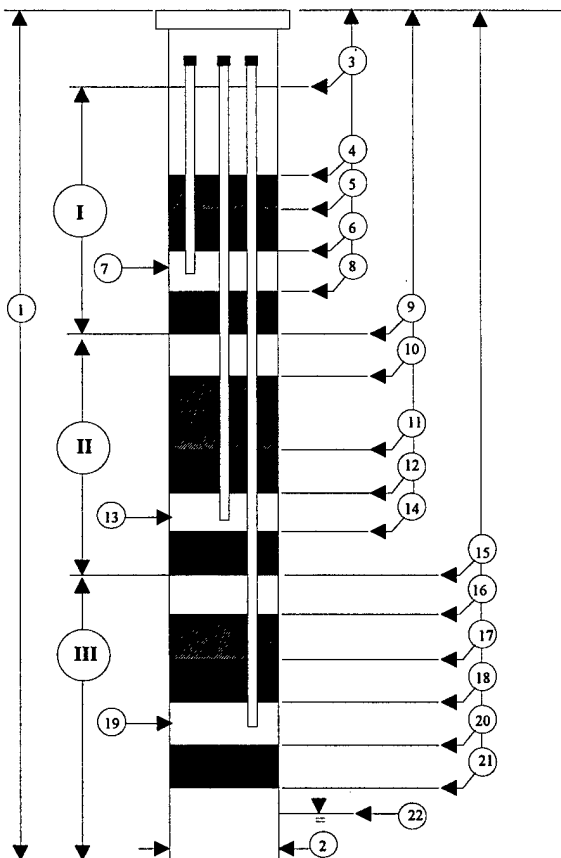
- 8" Cast iron manhole w/ galvanized steel, 8" diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

12AF

Data Entered by: ESH
Date Entered: 2/18/97

Date Installed: 10/10/95
Manhole Elevation: 257.28'



| | | |
|-----|--------------------------------|------|
| 1. | Depth of Borehole | 19.0 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | 3.2 |
| 5. | Depth to Top of Upper Seal I | 5.2 |
| 6. | Depth to Top of Sand I | 6.2 |
| 7. | Depth of Cluster Point I | 7.0 |
| 8. | Depth to Top of Lower Seal I | 7.4 |
| 9. | Depth to Top of Fill II | 9.6 |
| 10. | Depth to Top of Slurry II | 10.6 |
| 11. | Depth to Top of Upper Seal II | 16.5 |
| 12. | Depth to Top of Sand II | 17.6 |
| 13. | Depth of Cluster Point II | 18.0 |
| 14. | Depth to Top of Lower Seal II | 18.6 |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | N/A |
| 18. | Depth to Top of Sand III | N/A |
| 19. | Depth of Cluster Point III | N/A |
| 20. | Depth to Top of Lower Seal III | N/A |
| 21. | Depth to Top Remaining Fill | N/A |
| 22. | Depth to Water Table | N/A |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.

- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications

- 8" Cast iron manhole w/ galvanized steel, 8" diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

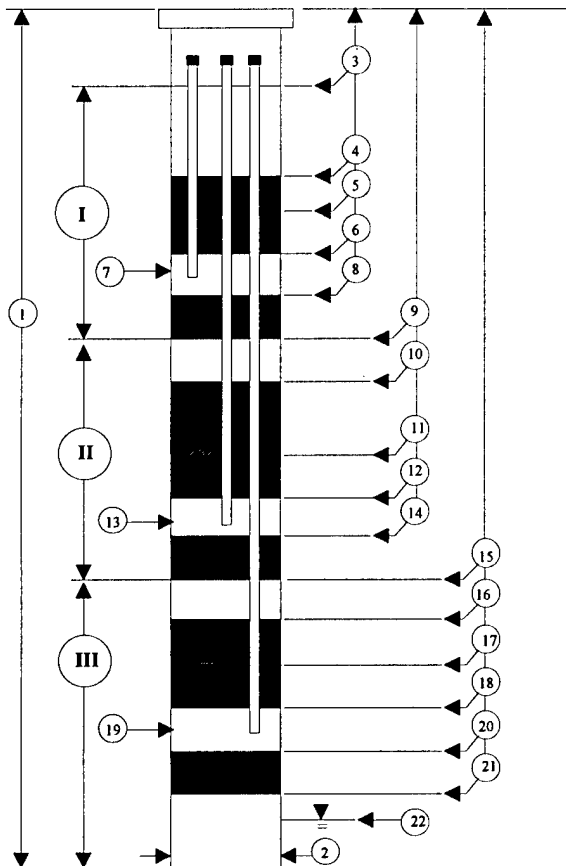
12AG

Data Entered by: ESH

Date Installed: 10/10/95

Date Entered: 2/18/97

Manhole Elevation: 256.42'



| | | |
|-----|--------------------------------|---------|
| 1. | Depth of Borehole | 48.0 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | N/A |
| 5. | Depth to Top of Upper Seal I | 1.8 |
| 6. | Depth to Top of Sand I | 3.0 |
| 7. | Depth of Cluster Point I | 3.4 |
| | Depth (ft MSL) | 241.42' |
| 8. | Depth to Top of Lower Seal I | 4.0 |
| 9. | Depth to Top of Fill II | N/A |
| 10. | Depth to Top of Slurry II | 6.0 |
| 11. | Depth to Top of Upper Seal II | 13.8 |
| 12. | Depth to Top of Sand II | 14.9 |
| 13. | Depth of Cluster Point II | 15.2 |
| | Depth (ft MSL) | 253.42' |
| 14. | Depth to Top of Lower Seal II | 15.8 |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | N/A |
| 18. | Depth to Top of Sand III | N/A |
| 19. | Depth of Cluster Point III | N/A |
| | Depth (ft MSL) | N/A |
| 20. | Depth to Top of Lower Seal III | N/A |
| 21. | Depth to Top Remaining Fill | 16.8 |
| 22. | Depth to Water Table | 40.0 |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.



- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications



8" Cast iron manhole
w/ galvanized steel, 8"
diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

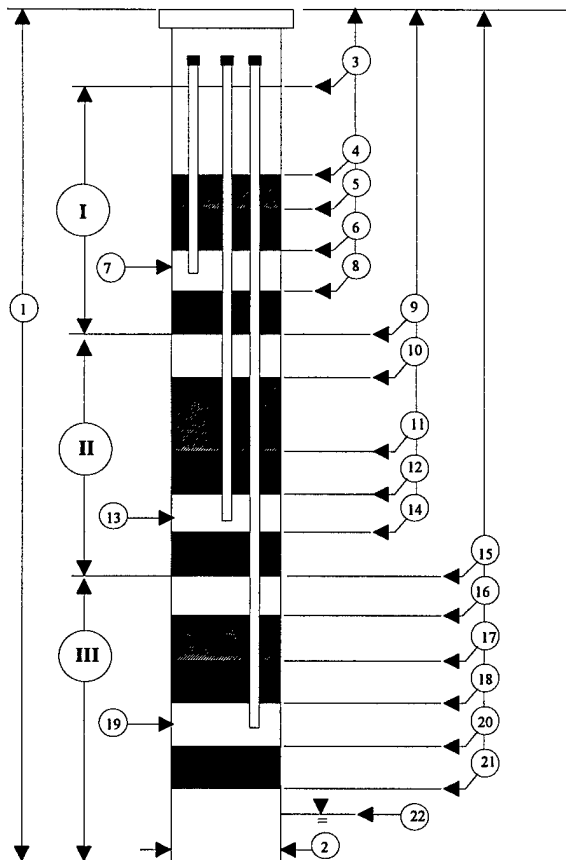
12AH

Data Entered by: ESH

Date Installed: 10/11/95

Date Entered: 2/18/97

Manhole Elevation: 256.28'



| | | |
|-----|--------------------------------|---------|
| 1. | Depth of Borehole | 31.8 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | 10.0 |
| 5. | Depth to Top of Upper Seal I | 11.0 |
| 6. | Depth to Top of Sand I | 3.0 |
| 7. | Depth of Cluster Point I | 12.4 |
| | Depth (ft MSL) | 226.28' |
| 8. | Depth to Top of Lower Seal I | 13.0 |
| 9. | Depth to Top of Fill II | 15.0 |
| 10. | Depth to Top of Slurry II | 21.6 |
| 11. | Depth to Top of Upper Seal II | 29.0 |
| 12. | Depth to Top of Sand II | 30.2 |
| 13. | Depth of Cluster Point II | 30.5 |
| | Depth (ft MSL) | 244.28' |
| 14. | Depth to Top of Lower Seal II | 31.0 |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | N/A |
| 18. | Depth to Top of Sand III | N/A |
| 19. | Depth of Cluster Point III | N/A |
| | Depth (ft MSL) | N/A |
| 20. | Depth to Top of Lower Seal III | N/A |
| 21. | Depth to Top Remaining Fill | N/A |
| 22. | Depth to Water Table | N/A |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.

- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications

- 8" Cast iron manhole w/ galvanized steel, 8" diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

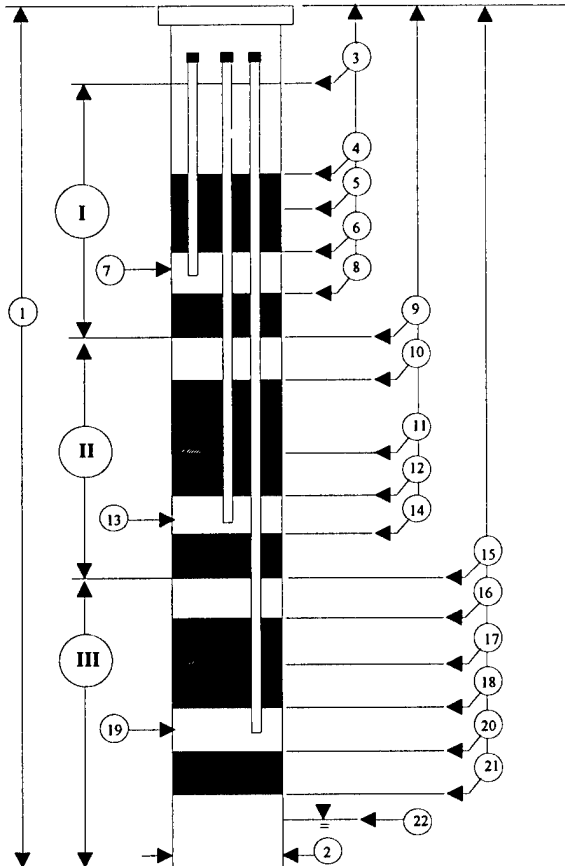
12AI

Data Entered by: ESH

Date Installed: 10/11/95

Date Entered: 2/18/97

Manhole Elevation: 256.20'



| | | |
|-----|--------------------------------|---------|
| 1. | Depth of Borehole | 31.0 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | 7.4 |
| 5. | Depth to Top of Upper Seal I | 8.6 |
| 6. | Depth to Top of Sand I | 9.6 |
| 7. | Depth of Cluster Point I | 10.0 |
| | Depth (ft MSL) | 227.70' |
| 8. | Depth to Top of Lower Seal I | 10.6 |
| 9. | Depth to Top of Fill II | 12.6 |
| 10. | Depth to Top of Slurry II | 20.8 |
| 11. | Depth to Top of Upper Seal II | 29.2 |
| 12. | Depth to Top of Sand II | 30.4 |
| 13. | Depth of Cluster Point II | 31.0 |
| | Depth (ft MSL) | 247.20' |
| 14. | Depth to Top of Lower Seal II | 31.6 |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | N/A |
| 18. | Depth to Top of Sand III | N/A |
| 19. | Depth of Cluster Point III | N/A |
| | Depth (ft MSL) | N/A |
| 20. | Depth to Top of Lower Seal III | N/A |
| 21. | Depth to Top Remaining Fill | N/A |
| 22. | Depth to Water Table | N/A |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.

- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications

- 8" Cast iron manhole w/ galvanized steel, 8" diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

12AJ

Data Entered by:

ESH

Date Installed:

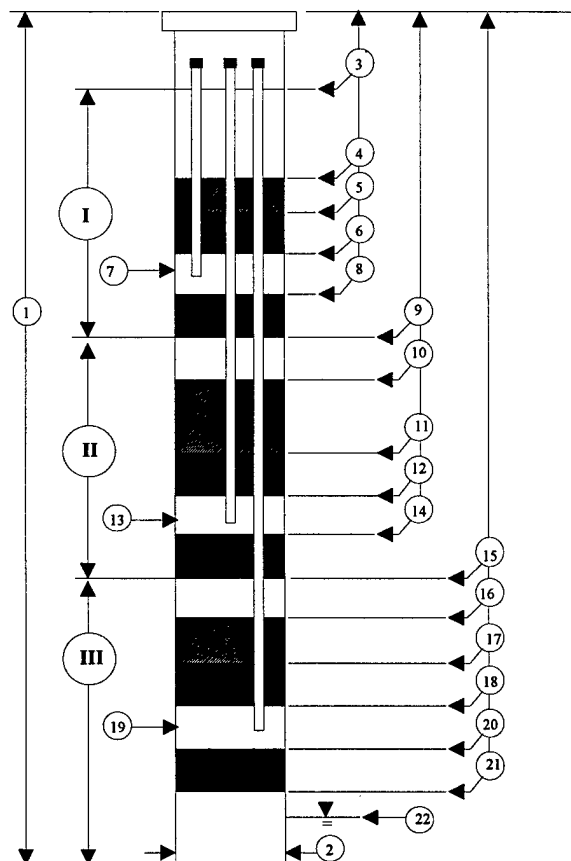
10/11/95

Date Entered:

2/18/97

Manhole Elevation:

255.85'



| | | |
|-----|--------------------------------|---------|
| 1. | Depth of Borehole | 20.5 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | 3.6 |
| 5. | Depth to Top of Upper Seal I | 5.0 |
| 6. | Depth to Top of Sand I | 6.2 |
| 7. | Depth of Cluster Point I | 6.7 |
| | Depth (ft MSL) | 237.85' |
| 8. | Depth to Top of Lower Seal I | 7.4 |
| 9. | Depth to Top of Fill II | 9.4 |
| 10. | Depth to Top of Slurry II | 10.0 |
| 11. | Depth to Top of Upper Seal II | 17.8 |
| 12. | Depth to Top of Sand II | 18.6 |
| 13. | Depth of Cluster Point II | 19.2 |
| | Depth (ft MSL) | 249.85' |
| 14. | Depth to Top of Lower Seal II | 19.8 |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | N/A |
| 18. | Depth to Top of Sand III | N/A |
| 19. | Depth of Cluster Point III | N/A |
| | Depth (ft MSL) | N/A |
| 20. | Depth to Top of Lower Seal III | N/A |
| 21. | Depth to Top Remaining Fill | N/A |
| 22. | Depth to Water Table | N/A |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.

- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications

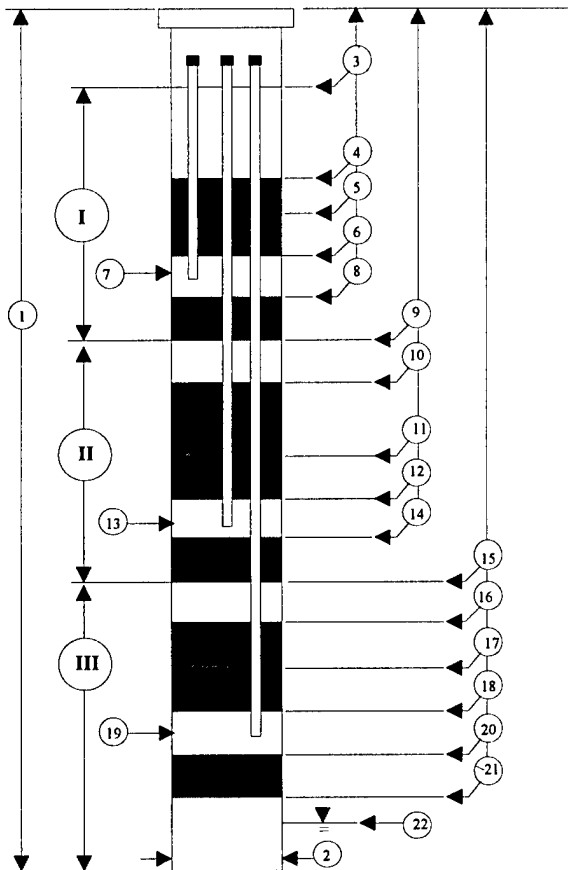
- 8" Cast iron manhole w/ galvanized steel, 8" diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

12AK

Data Entered by: ESH
Date Entered: 2/18/97

Date Installed: 10/11/95
Manhole Elevation: 256.49'



| | | |
|-----|--------------------------------|---------|
| 1. | Depth of Borehole | 47.0 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | 9.8 |
| 5. | Depth to Top of Upper Seal I | 10.9 |
| 6. | Depth to Top of Sand I | 12.0 |
| 7. | Depth of Cluster Point I | 12.4 |
| | Depth (ft MSL) | 226.49' |
| 8. | Depth to Top of Lower Seal I | 12.8 |
| 9. | Depth to Top of Fill II | 15.0 |
| 10. | Depth to Top of Slurry II | 20.6 |
| 11. | Depth to Top of Upper Seal II | 28.8 |
| 12. | Depth to Top of Sand II | 29.6 |
| 13. | Depth of Cluster Point II | 30.2 |
| | Depth (ft MSL) | 244.49' |
| 14. | Depth to Top of Lower Seal II | 30.7 |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | N/A |
| 18. | Depth to Top of Sand III | N/A |
| 19. | Depth of Cluster Point III | N/A |
| | Depth (ft MSL) | N/A |
| 20. | Depth to Top of Lower Seal III | N/A |
| 21. | Depth to Top Remaining Fill | 32.7 |
| 22. | Depth to Water Table | 40.0 |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.



- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications



8" Cast iron manhole
w/ galvanized steel, 8"
diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

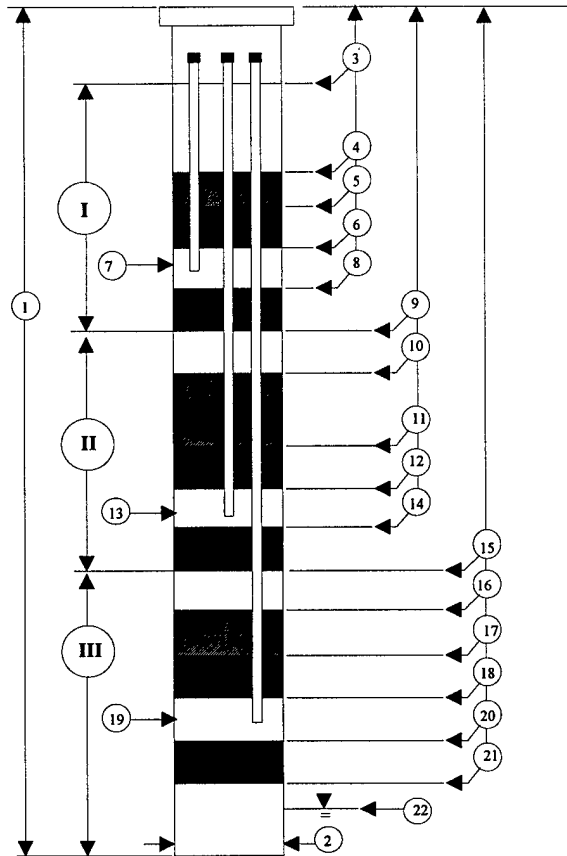
12AL

Data Entered by: ESH

Date Installed: 10/11/95

Date Entered: 2/18/97

Manhole Elevation: 257.55'



| | | |
|-----|--------------------------------|---------|
| 1. | Depth of Borehole | 18.0 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | N/A |
| 5. | Depth to Top of Upper Seal I | 2.0 |
| 6. | Depth to Top of Sand I | 2.9 |
| 7. | Depth of Cluster Point I | 3.4 |
| | Depth (ft MSL) | 242.55' |
| 8. | Depth to Top of Lower Seal I | 4.0 |
| 9. | Depth to Top of Fill II | 6.0 |
| 10. | Depth to Top of Slurry II | 8.0 |
| 11. | Depth to Top of Upper Seal II | 14.1 |
| 12. | Depth to Top of Sand II | 15.2 |
| 13. | Depth of Cluster Point II | 15.6 |
| | Depth (ft MSL) | 254.55' |
| 14. | Depth to Top of Lower Seal II | 16.2 |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | N/A |
| 18. | Depth to Top of Sand III | N/A |
| 19. | Depth of Cluster Point III | N/A |
| | Depth (ft MSL) | N/A |
| 20. | Depth to Top of Lower Seal III | N/A |
| 21. | Depth to Top Remaining Fill | 18.2 |
| 22. | Depth to Water Table | N/A |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.

- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications

- 8" Cast iron manhole w/ galvanized steel, 8" diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

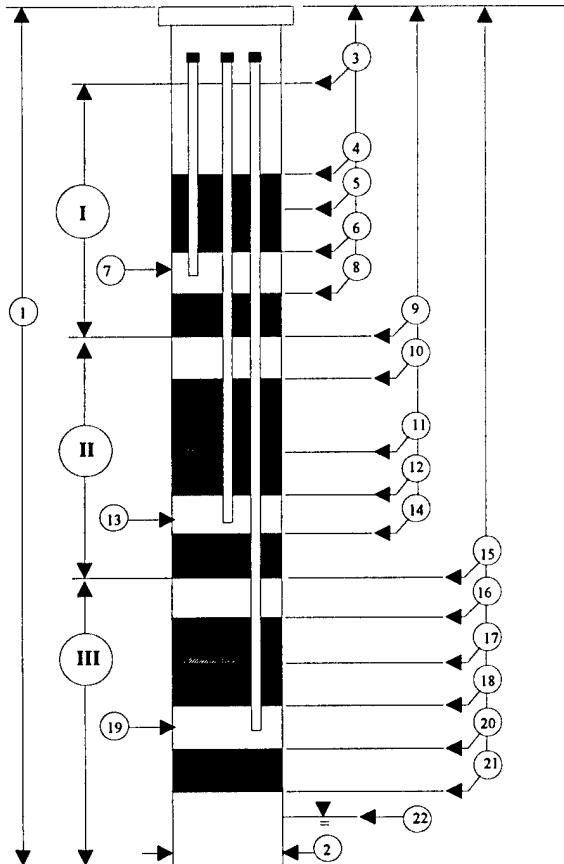
12AM

Data Entered by: ESH

Date Installed: 10/12/95

Date Entered: 2/18/97

Manhole Elevation: 256.49'



| | | |
|-----|--------------------------------|---------|
| 1. | Depth of Borehole | 48.0 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | 2.4 |
| 5. | Depth to Top of Upper Seal I | 33.6 |
| 6. | Depth to Top of Sand I | 34.6 |
| 7. | Depth of Cluster Point I | 35.2 |
| | Depth (ft MSL) | 211.99' |
| 8. | Depth to Top of Lower Seal I | 36.2 |
| 9. | Depth to Top of Fill II | N/A |
| 10. | Depth to Top of Slurry II | N/A |
| 11. | Depth to Top of Upper Seal II | N/A |
| 12. | Depth to Top of Sand II | 42.4 |
| 13. | Depth of Cluster Point II | 42.9 |
| | Depth (ft MSL) | 219.99' |
| 14. | Depth to Top of Lower Seal II | 43.6 |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | N/A |
| 18. | Depth to Top of Sand III | N/A |
| 19. | Depth of Cluster Point III | N/A |
| | Depth (ft MSL) | N/A |
| 20. | Depth to Top of Lower Seal III | N/A |
| 21. | Depth to Top Remaining Fill | N/A |
| 22. | Depth to Water Table | 40.0 |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.

- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications

- 8" Cast iron manhole w/ galvanized steel, 8" diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

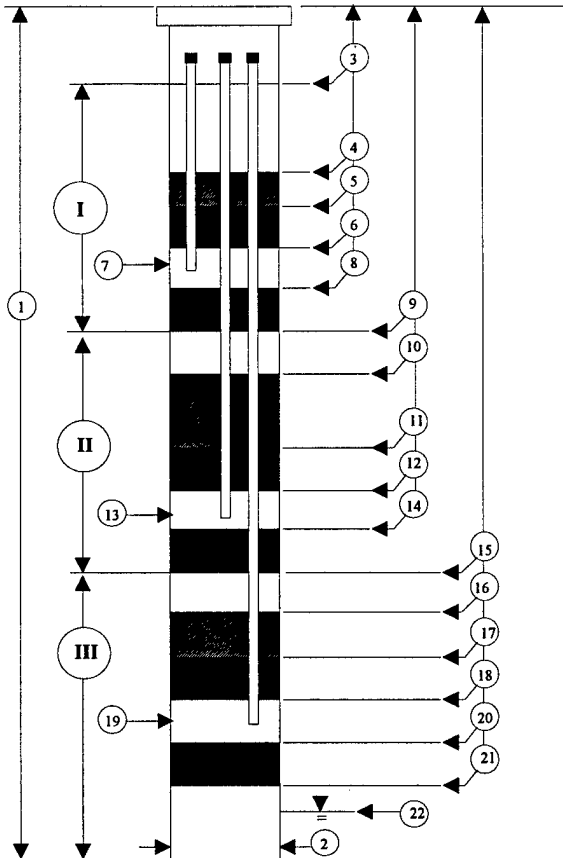
12AN

Data Entered by: ESH

Date Installed: 10/12/95

Date Entered: 2/18/97

Manhole Elevation: 251.29'



| | | |
|-----|------------------------------------|---------|
| 1. | Depth of Borehole | 32.5 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | 2.6 |
| 5. | Depth to Top of Upper Seal I | 5.4 |
| 6. | Depth to Top of Sand I | 6.2 |
| 7. | Depth of Cluster Point I | 6.7 |
| | Depth (ft MSL) | 224.29' |
| 8. | Depth to Top of Lower Seal I | 7.4 |
| 9. | Depth to Top of Fill II | 9.4 |
| 10. | Depth to Top of Slurry II | 13.2 |
| 11. | Depth to Top of Upper Seal II | 16.8 |
| 12. | Depth to Top of Sand II | 17.7 |
| 13. | Depth of Cluster Point II | 18.4 |
| | Depth (ft MSL) | 234.29' |
| 14. | Depth to Top of Lower Seal II | 19.6 |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | 22.1 |
| 17. | Depth to Top of Upper Seal III | 27.2 |
| 18. | Depth to Top of Sand III | 28.4 |
| 19. | Depth of Cluster Point III | 29 |
| | Depth (ft MSL) | 245.29' |
| 20. | Depth to Top of Lower Seal III | 29.6 |
| | NOTE: CAVED IN FROM 29.0' TO 31.0' | |
| 21. | Depth to Top Remaining Fill | N/A |
| 22. | Depth to Water Table | N/A |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point

- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications

- 8" Cast iron manhole w/ galvanized steel, 8" diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

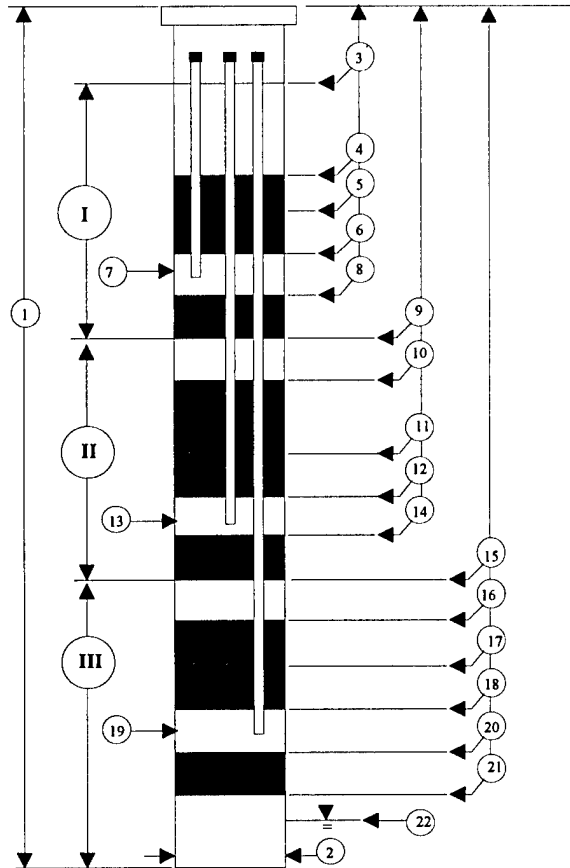
12AN

Data Entered by: ESH

Date Installed: 10/12/95

Date Entered: 2/18/97

Manhole Elevation: 251.29'



| | | |
|-----|------------------------------------|---------|
| 1. | Depth of Borehole | 32.5 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | 2.6 |
| 5. | Depth to Top of Upper Seal I | 5.4 |
| 6. | Depth to Top of Sand I | 6.2 |
| 7. | Depth of Cluster Point I | 6.7 |
| | Depth (ft MSL) | 224.29' |
| 8. | Depth to Top of Lower Seal I | 7.4 |
| 9. | Depth to Top of Fill II | 9.4 |
| 10. | Depth to Top of Slurry II | 13.2 |
| 11. | Depth to Top of Upper Seal II | 16.8 |
| 12. | Depth to Top of Sand II | 17.7 |
| 13. | Depth of Cluster Point II | 18.4 |
| | Depth (ft MSL) | 234.29' |
| 14. | Depth to Top of Lower Seal II | 19.6 |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | 22.1 |
| 17. | Depth to Top of Upper Seal III | 27.2 |
| 18. | Depth to Top of Sand III | 28.4 |
| 19. | Depth of Cluster Point III | 29 |
| | Depth (ft MSL) | 245.29' |
| 20. | Depth to Top of Lower Seal III | 29.6 |
| | NOTE: CAVED IN FROM 29.0' TO 31.0' | |
| 21. | Depth to Top Remaining Fill | N/A |
| 22. | Depth to Water Table | N/A |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point

- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications

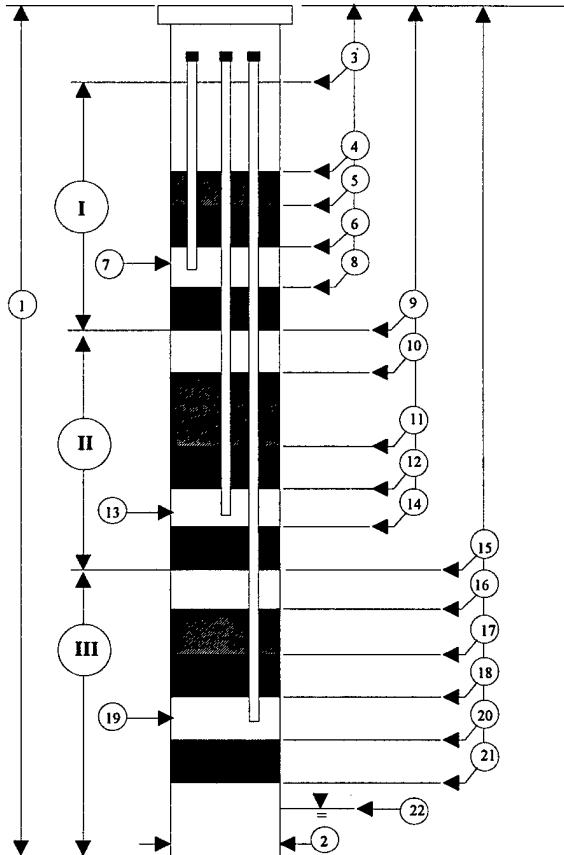
- 8" Cast iron manhole w/ galvanized steel, 8" diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

12AO

Data Entered by: ESH
Date Entered: 2/18/97

Date Installed: 10/11/95
Manhole Elevation: 255.58'



| | |
|--|---------|
| 1. Depth of Borehole | 31.5 |
| 2. Borehole Diameter (in) | 6.75 |
| 3. Depth to Top of Fill I | 0.4 |
| 4. Depth to Top of Slurry I | 8.4 |
| 5. Depth to Top of Upper Seal I | 11.5 |
| 6. Depth to Top of Sand I | 12.8 |
| 7. Depth of Cluster Point I Depth (ft MSL) | 225.58' |
| 8. Depth to Top of Lower Seal I | 13.6 |
| 9. Depth to Top of Fill II | 16.0 |
| 10. Depth to Top of Slurry II | 22.2 |
| 11. Depth to Top of Upper Seal II | 28.5 |
| 12. Depth to Top of Sand II | 29.5 |
| 13. Depth of Cluster Point II Depth (ft MSL) | 243.58' |
| 14. Depth to Top of Lower Seal II | 30.4 |
| 15. Depth to Top of Fill III | N/A |
| 16. Depth to Top of Slurry III | N/A |
| 17. Depth to Top of Upper Seal III | N/A |
| 18. Depth to Top of Sand III | N/A |
| 19. Depth of Cluster Point III Depth (ft MSL) | N/A |
| 20. Depth to Top of Lower Seal III | N/A |
| 21. Depth to Top Remaining Fill | 18.2 |
| 22. Depth to Water Table | N/A |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.



- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications



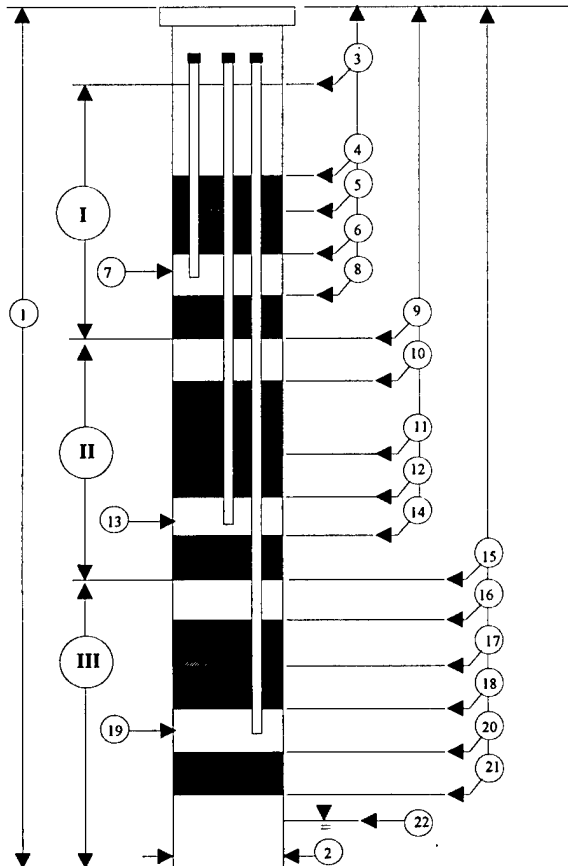
8" Cast iron manhole
w/ galvanized steel, 8"
diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

12AP

Data Entered by: ESH
Date Entered: 2/18/97

Date Installed: 10/13/95
Manhole Elevation: 255.98'



| | | |
|-----|--------------------------------|---------|
| 1. | Depth of Borehole | 45.0 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | 6.0 |
| 5. | Depth to Top of Upper Seal I | 8.0 |
| 6. | Depth to Top of Sand I | 9.0 |
| 7. | Depth of Cluster Point I | 9.4 |
| | Depth (ft MSL) | 231.98' |
| 8. | Depth to Top of Lower Seal I | 10.0 |
| 9. | Depth to Top of Fill II | 12.0 |
| 10. | Depth to Top of Slurry II | 15.0 |
| 11. | Depth to Top of Upper Seal II | 23.0 |
| 12. | Depth to Top of Sand II | 24.0 |
| 13. | Depth of Cluster Point II | 25.5 |
| | Depth (ft MSL) | 246.98' |
| 14. | Depth to Top of Lower Seal II | 24.8 |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | N/A |
| 18. | Depth to Top of Sand III | N/A |
| 19. | Depth of Cluster Point III | N/A |
| | Depth (ft MSL) | N/A |
| 20. | Depth to Top of Lower Seal III | N/A |
| 21. | Depth to Top Remaining Fill | 27.0 |
| 22. | Depth to Water Table | 40.0 |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.

- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications

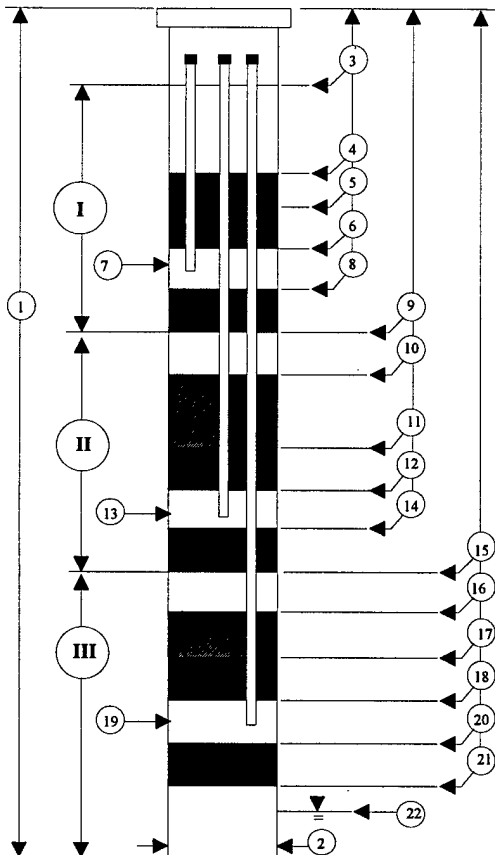
- 8" Cast iron manhole w/ galvanized steel, 8" diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

12AQ

Data Entered by: ESH
Date Entered: 2/18/97

Date Installed: 10/13/95
Manhole Elevation: 255.45'



| | | |
|-----|--|---------|
| 1. | Depth of Borehole | 28.0 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | N/A |
| 5. | Depth to Top of Upper Seal I | 7.7 |
| 6. | Depth to Top of Sand I | 8.4 |
| 7. | Depth of Cluster Point I Depth (ft MSL) | 231.45' |
| 8. | Depth to Top of Lower Seal I | 9.5 |
| 9. | Depth to Top of Fill II | 11.4 |
| 10. | Depth to Top of Slurry II | 14.3 |
| 11. | Depth to Top of Upper Seal II | 22.0 |
| 12. | Depth to Top of Sand II | 22.9 |
| 13. | Depth of Cluster Point II Depth (ft MSL) | 246.45' |
| 14. | Depth to Top of Lower Seal II | 23.8 |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | N/A |
| 18. | Depth to Top of Sand III | N/A |
| 19. | Depth of Cluster Point III Depth (ft MSL) | N/A |
| 20. | Depth to Top of Lower Seal III | N/A |
| 21. | Depth to Top Remaining Fill | 25.7 |
| 22. | Depth to Water Table | N/A |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.

- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications

- 8" Cast iron manhole w/ galvanized steel, 8" diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

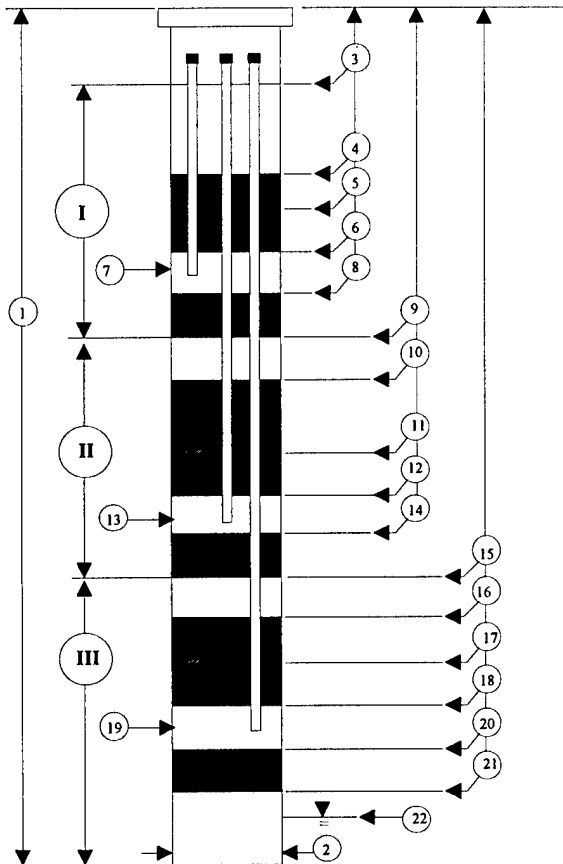
12AR

Data Entered by: ESH

Date Installed: 10/13/95

Date Entered: 2/18/97





Manhole Elevation: 255.58'




| | | |
|-----|--------------------------------|---------|
| 1. | Depth of Borehole | 47.0 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | N/A |
| 5. | Depth to Top of Upper Seal I | 1.8 |
| 6. | Depth to Top of Sand I | 3.0 |
| 7. | Depth of Cluster Point I | 3.4 |
| | Depth (ft MSL) | 240.58' |
| 8. | Depth to Top of Lower Seal I | 4.0 |
| 9. | Depth to Top of Fill II | N/A |
| 10. | Depth to Top of Slurry II | 6.0 |
| 11. | Depth to Top of Upper Seal II | 13.6 |
| 12. | Depth to Top of Sand II | 14.6 |
| 13. | Depth of Cluster Point II | 15.2 |
| | Depth (ft MSL) | 252.58' |
| 14. | Depth to Top of Lower Seal II | 15.6 |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | N/A |
| 18. | Depth to Top of Sand III | N/A |
| 19. | Depth of Cluster Point III | N/A |
| | Depth (ft MSL) | N/A |
| 20. | Depth to Top of Lower Seal III | N/A |
| 21. | Depth to Top Remaining Fill | 17.6 |
| 22. | Depth to Water Table | 40.0 |

All Dimensions in feet unless otherwise noted


Materials Legend

-  Fill: Clean Native Fill
-  Seal: Bentonite Pellets
-  Sand: Pool sand
-  Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.

-  - 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications

-  8" Cast iron manhole w/ galvanized steel, 8" diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

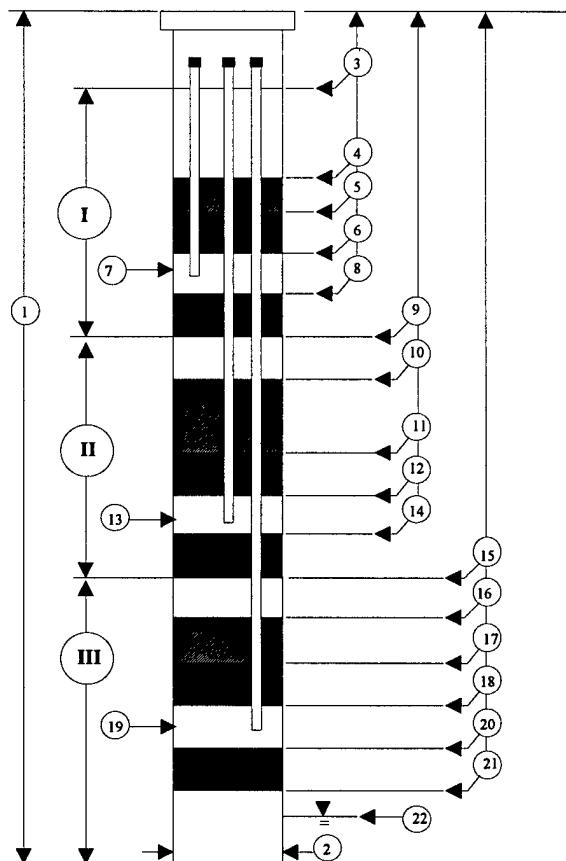
12AT

Data Entered by: ESH

Date Installed: 12/1/95

Date Entered: 2/18/97

Manhole Elevation: 250.18'



| | | |
|-----|--------------------------------|---------|
| 1. | Depth of Borehole | 40.5 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | N/A |
| 5. | Depth to Top of Upper Seal I | 27.0 |
| 6. | Depth to Top of Sand I | 30.5 |
| 7. | Depth of Cluster Point I | 31.0 |
| | Depth (ft MSL) | 219.18' |
| 8. | Depth to Top of Lower Seal I | N/A |
| 9. | Depth to Top of Fill II | N/A |
| 10. | Depth to Top of Slurry II | N/A |
| 11. | Depth to Top of Upper Seal II | N/A |
| 12. | Depth to Top of Sand II | N/A |
| 13. | Depth of Cluster Point II | N/A |
| | Depth (ft MSL) | N/A |
| 14. | Depth to Top of Lower Seal II | N/A |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | N/A |
| 18. | Depth to Top of Sand III | N/A |
| 19. | Depth of Cluster Point III | N/A |
| | Depth (ft MSL) | N/A |
| 20. | Depth to Top of Lower Seal III | N/A |
| 21. | Depth to Top Remaining Fill | 31.5 |
| 22. | Depth to Water Table | N/A |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.

- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications

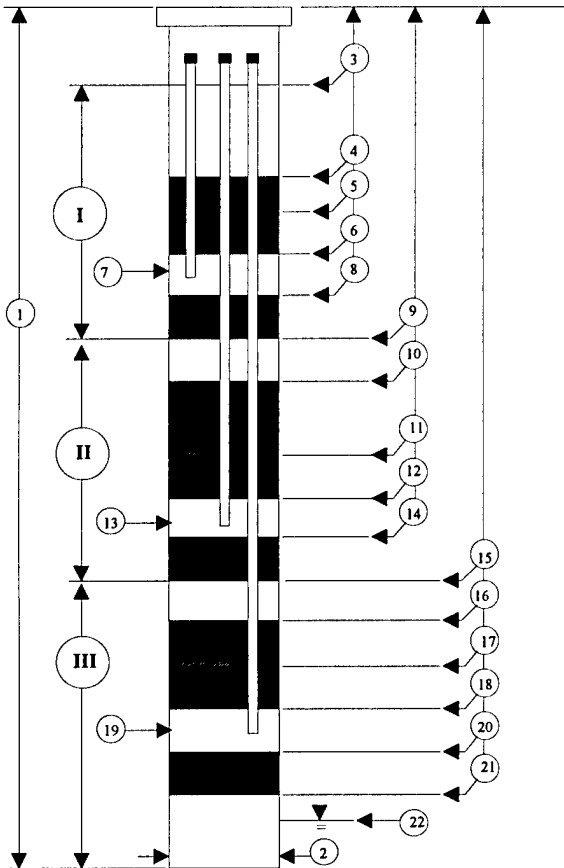
- 8" Cast iron manhole w/ galvanized steel, 8" diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

12AU

Data Entered by: ESH
Date Entered: 2/18/97

Date Installed: 6/5/96
Manhole Elevation: 256.53'



| | | |
|-----|--------------------------------|---------|
| 1. | Depth of Borehole | 47.0 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | 17.0 |
| 5. | Depth to Top of Upper Seal I | 33.9 |
| 6. | Depth to Top of Sand I | 33.5 |
| 7. | Depth of Cluster Point I | |
| | Depth (ft MSL) | 220.53' |
| 8. | Depth to Top of Lower Seal I | 36.3 |
| 9. | Depth to Top of Fill II | N/A |
| 10. | Depth to Top of Slurry II | N/A |
| 11. | Depth to Top of Upper Seal II | N/A |
| 12. | Depth to Top of Sand II | N/A |
| 13. | Depth of Cluster Point II | |
| | Depth (ft MSL) | N/A |
| 14. | Depth to Top of Lower Seal II | N/A |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | N/A |
| 18. | Depth to Top of Sand III | N/A |
| 19. | Depth of Cluster Point III | |
| | Depth (ft MSL) | N/A |
| 20. | Depth to Top of Lower Seal III | N/A |
| 21. | Depth to Top Remaining Fill | 36.9 |
| 22. | Depth to Water Table | N/A |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.

- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications

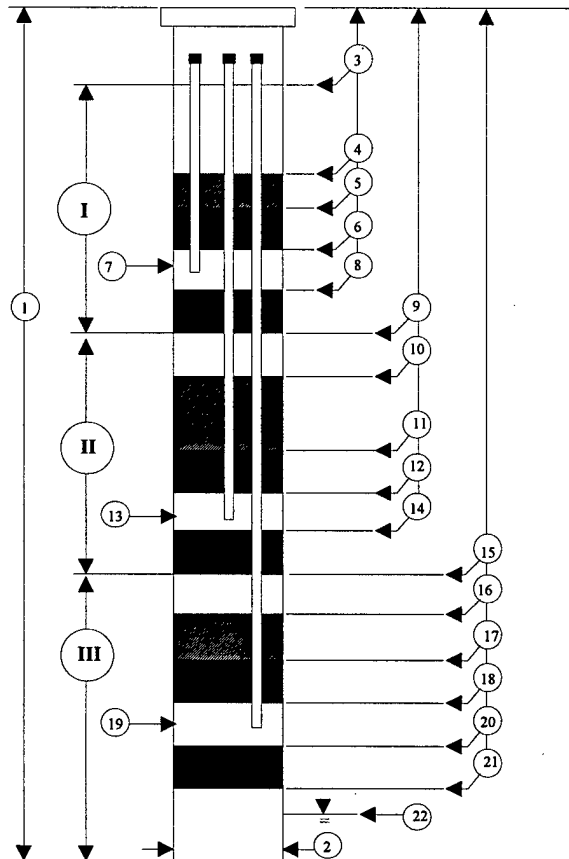
- 8" Cast iron manhole w/ galvanized steel, 8" diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

12AV

Data Entered by: ESH
Date Entered: 2/18/97

Date Installed: 6/5/96
Manhole Elevation: 256.36'



| | | |
|-----|--------------------------------|---------|
| 1. | Depth of Borehole | 49.0 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | 14.5 |
| 5. | Depth to Top of Upper Seal I | 34.0 |
| 6. | Depth to Top of Sand I | 35.0 |
| 7. | Depth of Cluster Point I | 35.7 |
| | Depth (ft MSL) | 220.66' |
| 8. | Depth to Top of Lower Seal I | N/A |
| 9. | Depth to Top of Fill II | N/A |
| 10. | Depth to Top of Slurry II | N/A |
| 11. | Depth to Top of Upper Seal II | N/A |
| 12. | Depth to Top of Sand II | N/A |
| 13. | Depth of Cluster Point II | N/A |
| | Depth (ft MSL) | N/A |
| 14. | Depth to Top of Lower Seal II | N/A |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | N/A |
| 18. | Depth to Top of Sand III | N/A |
| 19. | Depth of Cluster Point III | N/A |
| | Depth (ft MSL) | N/A |
| 20. | Depth to Top of Lower Seal III | N/A |
| 21. | Depth to Top Remaining Fill | 36.2 |
| 22. | Depth to Water Table | 40.0 |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.

- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications

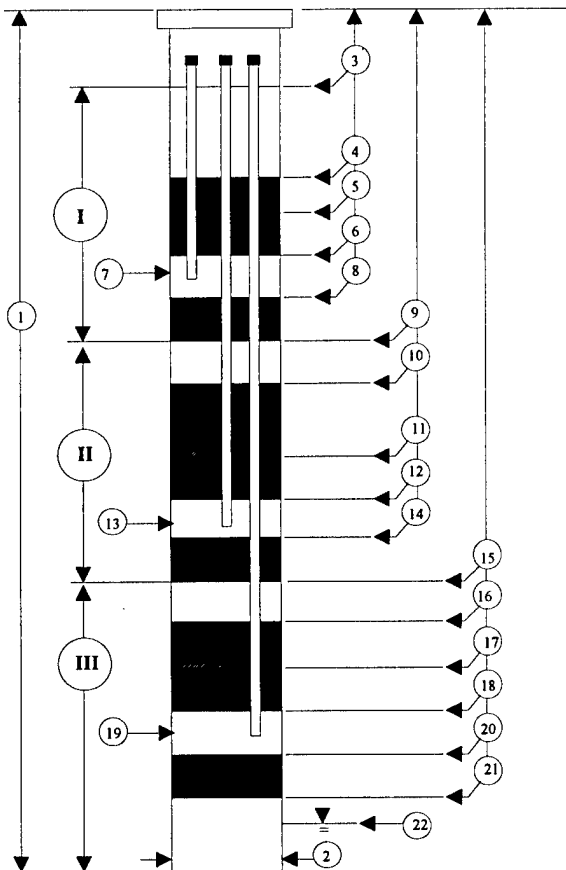
- 8" Cast iron manhole w/ galvanized steel, 8" diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

12AW

Data Entered by: ESH
Date Entered: 2/18/97

Date Installed: 6/5/96
Manhole Elevation: 256.32



| | | |
|-----|--------------------------------|--------|
| 1. | Depth of Borehole | 48.5 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | 4.0 |
| 5. | Depth to Top of Upper Seal I | 33.7 |
| 6. | Depth to Top of Sand I | 34.7 |
| 7. | Depth of Cluster Point I | 35.5 |
| | Depth (ft MSL) | 220.82 |
| 8. | Depth to Top of Lower Seal I | N/A |
| 9. | Depth to Top of Fill II | N/A |
| 10. | Depth to Top of Slurry II | N/A |
| 11. | Depth to Top of Upper Seal II | N/A |
| 12. | Depth to Top of Sand II | N/A |
| 13. | Depth of Cluster Point II | N/A |
| | Depth (ft MSL) | N/A |
| 14. | Depth to Top of Lower Seal II | N/A |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | N/A |
| 18. | Depth to Top of Sand III | N/A |
| 19. | Depth of Cluster Point III | N/A |
| | Depth (ft MSL) | N/A |
| 20. | Depth to Top of Lower Seal III | N/A |
| 21. | Depth to Top Remaining Fill | 36.2 |
| 22. | Depth to Water Table | 40.0 |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.



- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications



8" Cast iron manhole
w/ galvanized steel, 8"
diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

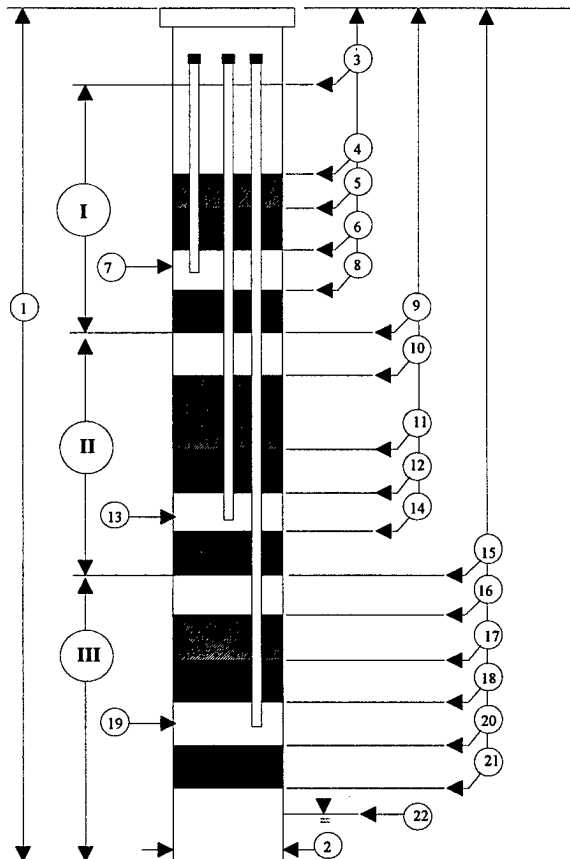
12AX

Data Entered by: ESH

Date Installed: 6/6/96

Date Entered: 2/18/97

Manhole Elevation: 249.97'



| | | |
|-----|--------------------------------|---------|
| 1. | Depth of Borehole | 37.0 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | 1.8 |
| 5. | Depth to Top of Upper Seal I | 7.0 |
| 6. | Depth to Top of Sand I | 9.0 |
| 7. | Depth of Cluster Point I | 9.8 |
| | Depth (ft MSL) | 240.17' |
| 8. | Depth to Top of Lower Seal I | 10.3 |
| 9. | Depth to Top of Fill II | 10.8 |
| 10. | Depth to Top of Slurry II | 17.5 |
| 11. | Depth to Top of Upper Seal II | 26.7 |
| 12. | Depth to Top of Sand II | 29.7 |
| 13. | Depth of Cluster Point II | 30.4 |
| | Depth (ft MSL) | 219.57' |
| 14. | Depth to Top of Lower Seal II | N/A |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | N/A |
| 18. | Depth to Top of Sand III | N/A |
| 19. | Depth of Cluster Point III | N/A |
| | Depth (ft MSL) | N/A |
| 20. | Depth to Top of Lower Seal III | N/A |
| 21. | Depth to Top Remaining Fill | 32.0 |
| 22. | Depth to Water Table | 31.5 |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.

- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications

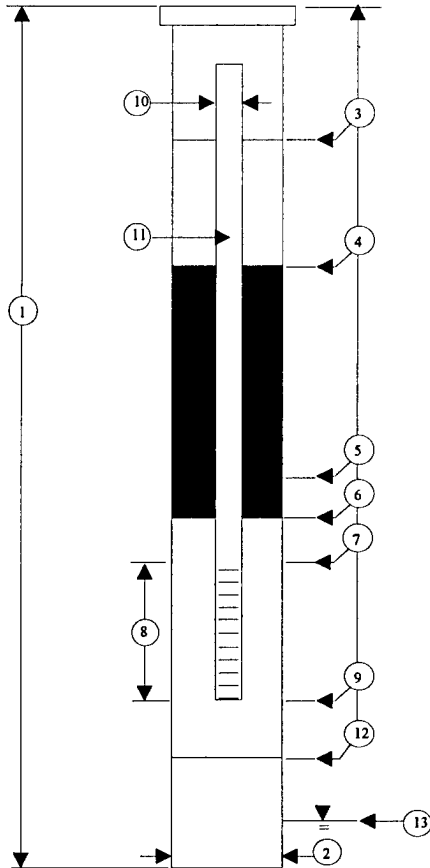
- 8" Cast iron manhole w/ galvanized steel, 8" diameter, 18" deep collar

Construction Details For Borehole/Well

12AY

Data Entered by: ESH
Date Entered: 2/18/97

Date Installed: 6/6/96
Manhole Elevation: 255.46'



| | | |
|-----|-----------------------------|---------|
| 1. | Depth of Borehole | 53 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill | 0.5 |
| 4. | Depth to Top of Slurry | N/A |
| 5. | Depth to Top of Upper Seal | 31.0 |
| 6. | Depth to Top of Sand | 35.0 |
| 8. | Depth to Top of Well Screen | 37.0 |
| | Depth (ft MSL) | 218.46' |
| 8. | Well Screen Length | 15.0 |
| 7. | Depth of Well Bottom | 52.0 |
| 9. | Diameter of Well (in) | 2.0 |
| 10. | Well Material | PVC |
| 21. | Depth to Top Remaining Fill | N/A |
| 22. | Depth to Water Table | 37.0 |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Manhole Specifications



8" Cast iron manhole
w/ galvanized steel, 8"
diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

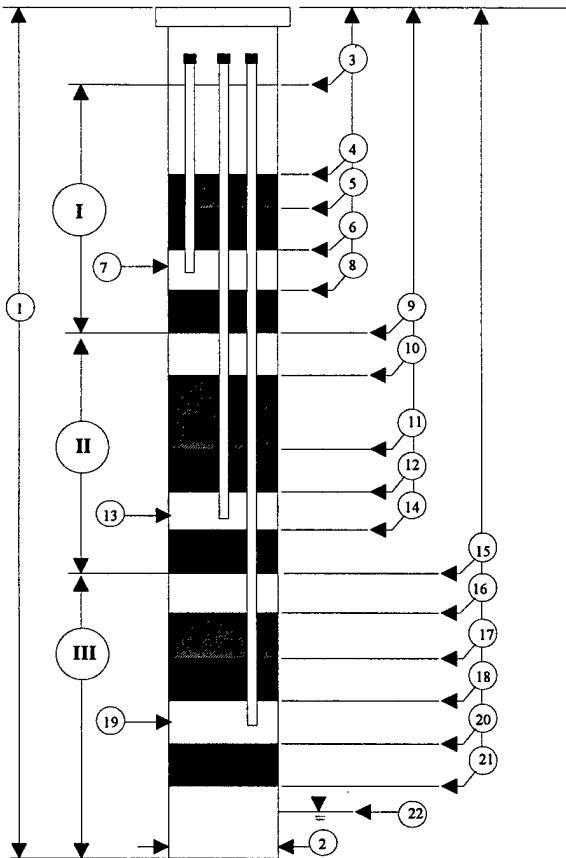
12AZ

Data Entered by: ESH

Date Installed: 6/7/96

Date Entered: 2/18/97

Manhole Elevation: 254.18



| | | |
|-----|---|--------|
| 1. | Depth of Borehole | 51.0 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | N/A |
| 5. | NOTE: CAVED IN FROM 32.3' TO 8.5' Depth to Top of Upper Seal I | 32.3 |
| 6. | Depth to Top of Sand I | 34.3 |
| 7. | Depth of Cluster Point I | 35.3 |
| | Depth (ft MSL) | 218.88 |
| 8. | Depth to Top of Lower Seal I | N/A |
| 9. | Depth to Top of Fill II | N/A |
| 10. | Depth to Top of Slurry II | N/A |
| 11. | Depth to Top of Upper Seal II | N/A |
| 12. | Depth to Top of Sand II | N/A |
| 13. | Depth of Cluster Point II | N/A |
| | Depth (ft MSL) | N/A |
| 14. | Depth to Top of Lower Seal II | N/A |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | N/A |
| 18. | Depth to Top of Sand III | N/A |
| 19. | Depth of Cluster Point III | N/A |
| | Depth (ft MSL) | N/A |
| 20. | Depth to Top of Lower Seal III | N/A |
| 21. | Depth to Top Remaining Fill | 35.5 |
| 22. | Depth to Water Table | 40.0 |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.

- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications

- 8" Cast iron manhole w/ galvanized steel, 8" diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

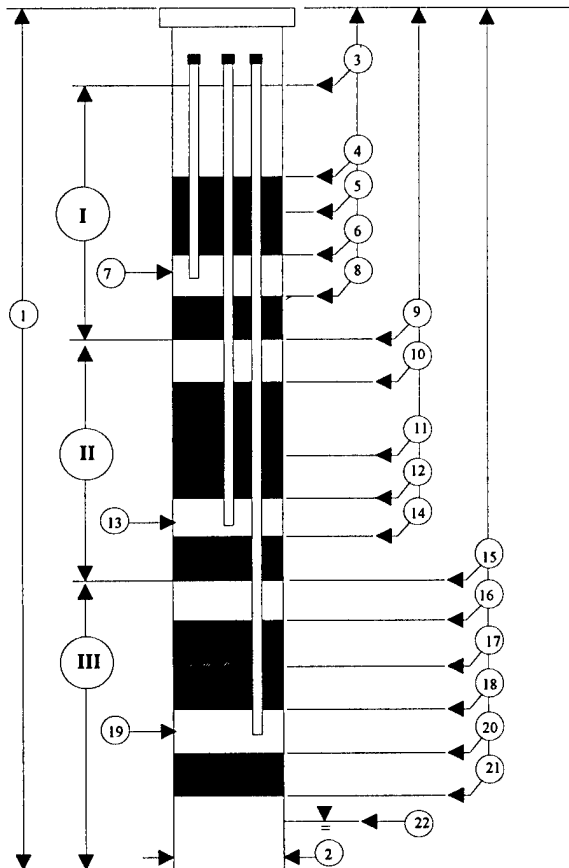
12BA

Data Entered by: ESH

Date Installed: 6/7/96

Date Entered: 2/18/97

Manhole Elevation: 255.86'



| | | |
|-----|--------------------------------|--------|
| 1. | Depth of Borehole | 53.0 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | 6.5 |
| 5. | Depth to Top of Upper Seal I | 32.5 |
| 6. | Depth to Top of Sand I | 35.1 |
| 7. | Depth of Cluster Point I | 36.0 |
| | Depth (ft MSL) | 219.86 |
| 8. | Depth to Top of Lower Seal I | N/A |
| 9. | Depth to Top of Fill II | N/A |
| 10. | Depth to Top of Slurry II | N/A |
| 11. | Depth to Top of Upper Seal II | N/A |
| 12. | Depth to Top of Sand II | N/A |
| 13. | Depth of Cluster Point II | N/A |
| | Depth (ft MSL) | N/A |
| 14. | Depth to Top of Lower Seal II | N/A |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | N/A |
| 18. | Depth to Top of Sand III | N/A |
| 19. | Depth of Cluster Point III | N/A |
| | Depth (ft MSL) | N/A |
| 20. | Depth to Top of Lower Seal III | N/A |
| 21. | Depth to Top Remaining Fill | 36.2 |
| 22. | Depth to Water Table | 40.0 |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.

- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

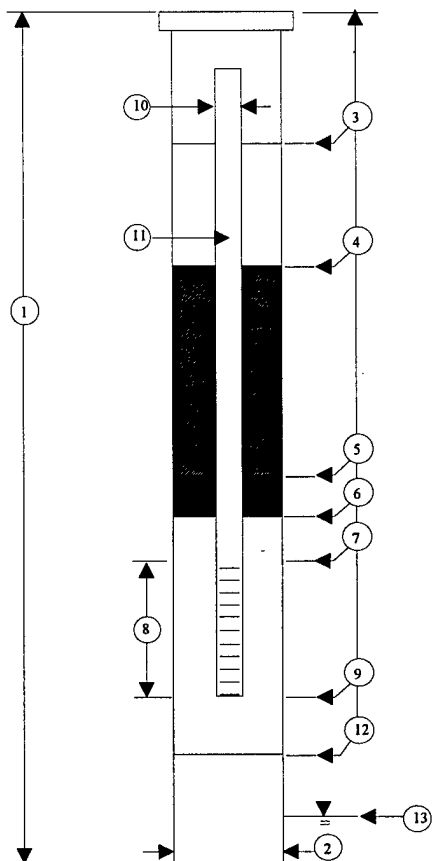
Manhole Specifications

- 8" Cast iron manhole w/ galvanized steel, 8" diameter, 18" deep collar

VENT 1

Date Installed: 11/30/95


Manhole Elevation: 256.26'



- | | | |
|-----|-----------------------------|---------|
| 1. | Depth of Borehole | 42.5 |
| 2. | Borehole Diameter (in) | 9.9 |
| 3. | Depth to Top of Fill | N/A |
| 4. | Depth to Top of Slurry | 0.5 |
| 5. | Depth to Top of Upper Seal | 34.5 |
| 6. | Depth to Top of Sand | 37.5 |
| 7. | Depth to Top of Well Screen | 37.0 |
| | Depth (ft MSL) | 219.26' |
| 8. | Well Screen Length | 5.0 |
| 9. | Depth of Well Bottom | 42.0 |
| 10. | Diameter of Well (in) | 3.0 |
| 11. | Well Material | PVC |
| 12. | Depth to Top Remaining Fill | N/A |
| 13. | Depth to Water Table | 39.5 |

All Dimensions in feet unless otherwise noted

Manhole Specifications

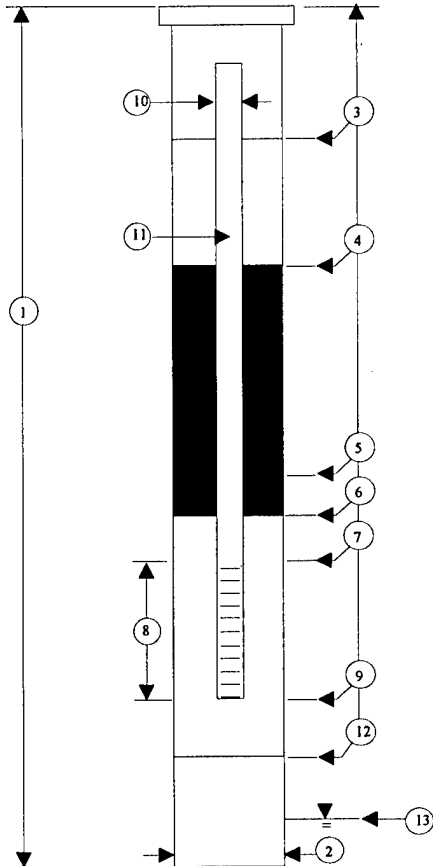
- 
- 10" Cast iron manhole
w/ galvanized steel, 10"
diameter, 18" deep collar

Construction Details For Borehole/Well

VENT 2

Data Entered by: ESH
Date Entered: 2/18/97

Date Installed: 11/30/95
Manhole Elevation: 256.30'



| | | |
|-----|-----------------------------|---------|
| 1. | Depth of Borehole | 43 |
| 2. | Borehole Diameter (in) | 9.9 |
| 3. | Depth to Top of Fill | N/A |
| 4. | Depth to Top of Slurry | 0.5 |
| 5. | Depth to Top of Upper Seal | 34.5 |
| 6. | Depth to Top of Sand | 37.5 |
| 7. | Depth to Top of Well Screen | 37.0 |
| | Depth (ft MSL) | 219.30' |
| 8. | Well Screen Length | 5.0 |
| 9. | Depth of Well Bottom | 42.0 |
| 10. | Diameter of Well (in) | 3.0 |
| 11. | Well Material | PVC |
| 12. | Depth to Top Remaining Fill | 42.5 |
| 13. | Depth to Water Table | 39.5 |

All Dimensions in feet unless otherwise noted

Materials Legend

- Fill: Clean Native Fill
- Seal: Bentonite Pellets
- Sand: Pool sand
- Slurry: Bentonite Slurry

Manhole Specifications



10" Cast iron manhole
w/ galvanized steel, 10"
diameter, 18" deep collar

Construction Details For Borehole/Well

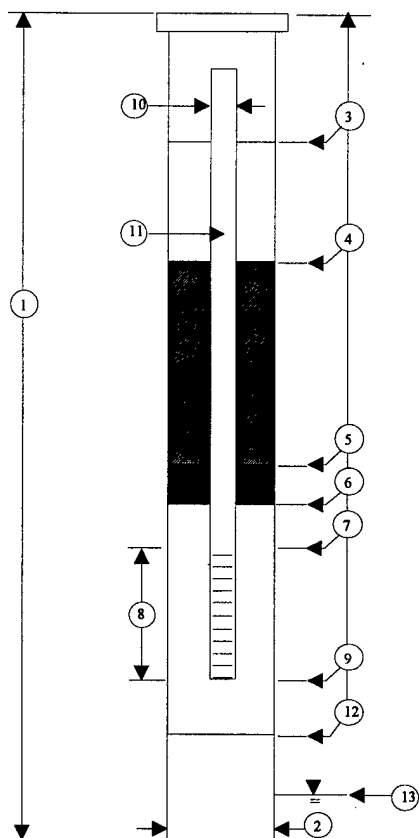
SPARGE 1

Data Entered by: ESH

Date Installed: 12/1/95

Date Entered: 2/18/97

Manhole Elevation: 256.30'







| | |
|---------------------------------|---------|
| 1. Depth of Borehole | 50 |
| 2. Borehole Diameter (in) | 9.9 |
| 3. Depth to Top of Fill | 0.5 |
| 4. Depth to Top of Slurry | 5.0 |
| 5. Depth to Top of Upper Seal | 36.0 |
| 6. Depth to Top of Sand | 43.0 |
| 7. Depth to Top of Well Screen | 43.1 |
| Depth (ft MSL) | 213.20' |
| 8. Well Screen Length | 0.7 |
| 9. Depth of Well Bottom | 43.8 |
| 10. Diameter of Well (in) | 0.8 |
| 11. Well Material | PVC |
| 12. Depth to Top Remaining Fill | N/A |
| 13. Depth to Water Table | 39.0 |

All Dimensions in feet unless otherwise noted

NOTE: SHARES COMMON HOLE W/ SPARGE 2

Materials Legend

-  — Fill: Clean Native Fill
-  — Seal: Bentonite Pellets
-  — Sand: Pool sand
-  — Slurry: Bentonite Slurry

Manhole Specifications



10" Cast iron manhole
w/ galvanized steel, 10"
diameter, 18" deep collar

Construction Details For Borehole/Soil Gas Cluster

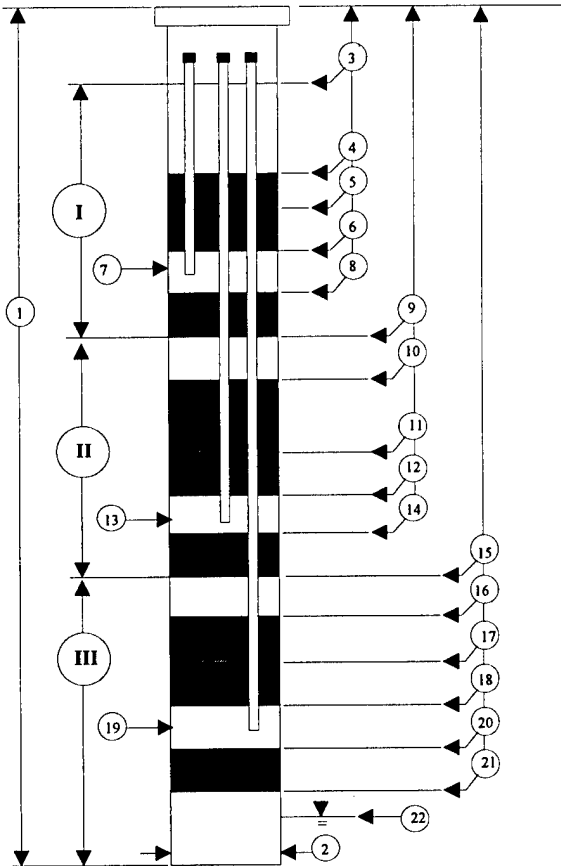
CONTROL

Data Entered by: ESH

Date Installed: 10/12/95

Date Entered: 2/18/97





Manhole Elevation: 244.12'



| | | |
|-----|--------------------------------|---------|
| 1. | Depth of Borehole | 32.0 |
| 2. | Borehole Diameter (in) | 6.75 |
| 3. | Depth to Top of Fill I | 0.4 |
| 4. | Depth to Top of Slurry I | 9.0 |
| 5. | Depth to Top of Upper Seal I | 11.0 |
| 6. | Depth to Top of Sand I | 12.0 |
| 7. | Depth of Cluster Point I | 12.6 |
| | Depth (ft MSL) | 220.12' |
| 8. | Depth to Top of Lower Seal I | 13.2 |
| 9. | Depth to Top of Fill II | N/A |
| 10. | Depth to Top of Slurry II | 15.2 |
| 11. | Depth to Top of Upper Seal II | 23.0 |
| 12. | Depth to Top of Sand II | 24.2 |
| 13. | Depth of Cluster Point II | 24.6 |
| | Depth (ft MSL) | 232.12' |
| 14. | Depth to Top of Lower Seal II | 25.3 |
| 15. | Depth to Top of Fill III | N/A |
| 16. | Depth to Top of Slurry III | N/A |
| 17. | Depth to Top of Upper Seal III | N/A |
| 18. | Depth to Top of Sand III | N/A |
| 19. | Depth of Cluster Point III | N/A |
| | Depth (ft MSL) | N/A |
| 20. | Depth to Top of Lower Seal III | N/A |
| 21. | Depth to Top Remaining Fill | 27.2 |
| 22. | Depth to Water Table | N/A |

All Dimensions in feet unless otherwise noted

Materials Legend

-  — Fill: Clean Native Fill
-  — Seal: Bentonite Pellets
-  — Sand: Pool sand
-  — Slurry: Bentonite Slurry

Permanent Soil Gas Monitoring Point.



- 1/4" Swagelok fitting @ top
- Riser, 1/4" SS tubing.
- Sintered SS intake filter @ bottom

Manhole Specifications



8" Cast iron manhole
w/ galvanized steel, 8"
diameter, 18" deep collar

APPENDIX III GRAIN SIZE DATA

| Sieve Size | Boring | | SPK1 | | Sample | | 133 |
|------------|--------------|----------|------------|------------|-------------|------------|------|
| | Depth (m) | | 0.0 - 0.46 | | Dry Wt. (g) | | |
| | Soil Wt. (g) | Retained | % Retained | % Retained | Accum. | % Retained | |
| 3/8 | 27.1 | 18.1 | 66.8 | 18.1 | 18.1 | 66.8 | 81.9 |
| 4 | 14.0 | 9.3 | 66.4 | 27.4 | 27.4 | 66.4 | 72.6 |
| 10 | 10.8 | 7.2 | 66.7 | 34.6 | 34.6 | 66.7 | 65.4 |
| 20 | 15.6 | 10.4 | 66.7 | 45.0 | 45.0 | 66.7 | 55.0 |
| 40 | 32.0 | 21.3 | 66.6 | 66.3 | 66.3 | 66.6 | 33.7 |
| 60 | 27.1 | 18.1 | 66.6 | 84.4 | 84.4 | 66.6 | 15.6 |
| 80 | 9.7 | 6.5 | 66.5 | 90.9 | 90.9 | 66.5 | 9.1 |
| 100 | 3.0 | 2.0 | 66.7 | 92.9 | 92.9 | 66.7 | 7.1 |
| 200 | 7.2 | 4.8 | 66.7 | 97.7 | 97.7 | 66.7 | 2.3 |
| Pan | 3.5 | 2.3 | 66.7 | 100.0 | 100.0 | 66.7 | 0.0 |
| Total | 150.0 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 136 |
|---------------|--------------|----------|-------------|------------|-------------|------------|------|
| | Depth (m) | | 1.37 - 1.83 | | Dry Wt. (g) | | |
| | Soil Wt. (g) | Retained | % Retained | % Retained | Accum. | % Retained | |
| 3/8 | 6.5 | 6.5 | 1.3 | 1.3 | 1.3 | 1.3 | 98.7 |
| 4 | 45.8 | 45.8 | 9.1 | 9.1 | 10.4 | 10.4 | 89.6 |
| 10 | 78.2 | 78.2 | 15.6 | 15.6 | 26.0 | 26.0 | 74.0 |
| 20 | 82.3 | 82.3 | 16.4 | 16.4 | 42.4 | 42.4 | 57.6 |
| 40 | 131.5 | 131.5 | 26.2 | 26.2 | 68.7 | 68.7 | 31.3 |
| 60 | 100.2 | 100.2 | 20.0 | 20.0 | 88.7 | 88.7 | 11.3 |
| 80 | 23.0 | 23.0 | 4.6 | 4.6 | 93.3 | 93.3 | 6.7 |
| 100 | 7.1 | 7.1 | 1.4 | 1.4 | 94.7 | 94.7 | 5.3 |
| 200 | 14.3 | 14.3 | 2.9 | 2.9 | 97.5 | 97.5 | 2.5 |
| Pan | 12.4 | 12.4 | 2.5 | 2.5 | 100.0 | 100.0 | 0.0 |
| Total | 501.3 | 501.3 | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 139 |
|------------|-----------|--------------------------|-------------|------------|-----------------------|------------|-----|
| | Depth (m) | Soil Wt. (g) Retained | 2.74 - 3.20 | | Dry Wt. (g) Accum. | % Retained | |
| | | | % Retained | % Retained | | | |
| 3/8 | | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | |
| 4 | | 6.4 | 1.3 | 1.3 | 1.3 | 98.7 | |
| 10 | | 12.2 | 2.5 | 3.8 | 3.8 | 96.2 | |
| 20 | | 53.5 | 10.8 | 14.6 | 14.6 | 85.4 | |
| 40 | | 194.0 | 39.3 | 53.9 | 53.9 | 46.1 | |
| 60 | | 143.2 | 29.0 | 82.9 | 82.9 | 17.1 | |
| 80 | | 39.5 | 8.0 | 90.9 | 90.9 | 9.1 | |
| 100 | | 13.9 | 2.8 | 93.7 | 93.7 | 6.3 | |
| 200 | | 19.3 | 3.9 | 97.6 | 97.6 | 2.4 | |
| Pan | | 11.8 | 2.4 | 100.0 | 100.0 | 0.0 | |
| Total | | 493.8 | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 134 |
|---------------|--------------|----------|-------------|------------|----------------------|---------|-----|
| | Depth (m) | | 0.46 - 0.91 | | Dry Wt. (g) | | |
| | Soil Wt. (g) | Retained | % Retained | % Retained | Accum. % Retained | % Finer | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | |
| 4 | 8.7 | 2.7 | 2.7 | 2.7 | 2.7 | 97.3 | |
| 10 | 31.1 | 9.7 | 9.7 | 12.4 | 12.4 | 87.6 | |
| 20 | 53.2 | 16.5 | 16.5 | 28.9 | 28.9 | 71.1 | |
| 40 | 95.9 | 29.8 | 29.8 | 58.6 | 58.6 | 41.4 | |
| 60 | 91.5 | 28.4 | 28.4 | 87.0 | 87.0 | 13.0 | |
| 80 | 18.9 | 5.9 | 5.9 | 92.9 | 92.9 | 7.1 | |
| 100 | 4.7 | 1.5 | 1.5 | 94.4 | 94.4 | 5.6 | |
| 200 | 10.3 | 3.2 | 3.2 | 97.5 | 97.5 | 2.5 | |
| Pan | 7.9 | 2.5 | 2.5 | 100.0 | 100.0 | 0.0 | |
| Total | 322.2 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 137 |
|------------|--------------|----------|-------------|------------|-------------|------------|------|
| | Depth (m) | | 1.83 - 2.29 | | Dry Wt. (g) | | |
| | Soil Wt. (g) | Retained | % Retained | % Retained | Accum. | % Retained | |
| 3/8 | 6.6 | | 1.3 | | 1.3 | | 98.7 |
| 4 | 5.8 | | 1.2 | | 2.5 | | 97.5 |
| 10 | 8.8 | | 1.8 | | 4.2 | | 95.8 |
| 20 | 53.2 | | 10.6 | | 14.8 | | 85.2 |
| 40 | 220.2 | | 43.8 | | 58.6 | | 41.4 |
| 60 | 137.9 | | 27.4 | | 86.0 | | 14.0 |
| 80 | 34.6 | | 6.9 | | 92.9 | | 7.1 |
| 100 | 12.4 | | 2.5 | | 95.4 | | 4.6 |
| 200 | 16.5 | | 3.3 | | 98.6 | | 1.4 |
| Pan | 6.8 | | 1.4 | | 100.0 | | 0.0 |
| Total | 502.8 | | | | | | |

| Sieve Size | Boring | | SPK1 3.20 - 3.66 | | Sample | | 140 |
|------------|-----------|--------------------------|---------------------|------------|-----------------------|------------|---------|
| | Depth (m) | Soil Wt. (g) Retained | 3.20 - 3.66 | | Dry Wt. (g) Accum. | % Retained | |
| | | | % Retained | % Retained | | | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | % Finer |
| 4 | 8.6 | 1.7 | 1.7 | 1.7 | 5.0 | 98.3 | |
| 10 | 16.2 | 3.3 | 3.3 | 5.0 | 17.4 | 95.0 | |
| 20 | 61.1 | 12.4 | 12.4 | 17.4 | 52.8 | 82.6 | |
| 40 | 175.0 | 35.4 | 35.4 | 52.8 | 80.7 | 47.2 | |
| 60 | 138.2 | 28.0 | 28.0 | 80.7 | 89.2 | 19.3 | |
| 80 | 41.7 | 8.4 | 8.4 | 89.2 | 92.3 | 10.8 | |
| 100 | 15.6 | 3.2 | 3.2 | 92.3 | 97.3 | 7.7 | |
| 200 | 24.8 | 5.0 | 5.0 | 97.3 | 100.0 | 2.7 | |
| Pan | 13.2 | 2.7 | 2.7 | 100.0 | | 0.0 | |
| Total | 494.4 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 135 |
|------------|--------------|----------|-------------|------------|-------------|------------|------|
| | Depth (m) | | 0.91 - 1.37 | | Dry Wt. (g) | | |
| | Soil Wt. (g) | Retained | % Retained | % Retained | Accum. | % Retained | |
| 3/8 | 20.6 | 8.4 | 40.8 | 8.4 | 8.4 | 40.8 | 91.6 |
| 4 | 6.1 | 2.5 | 40.8 | 10.9 | 10.9 | 40.8 | 89.1 |
| 10 | 11.4 | 4.7 | 41.2 | 15.6 | 15.6 | 41.2 | 84.4 |
| 20 | 27.9 | 11.4 | 40.9 | 27.0 | 27.0 | 40.9 | 73.0 |
| 40 | 72.6 | 29.7 | 40.8 | 56.7 | 56.7 | 40.8 | 43.3 |
| 60 | 63.9 | 26.2 | 40.9 | 82.9 | 82.9 | 40.9 | 17.1 |
| 80 | 17.6 | 7.2 | 40.9 | 90.1 | 90.1 | 40.9 | 9.9 |
| 100 | 7.3 | 3.0 | 40.9 | 93.1 | 93.1 | 40.9 | 6.9 |
| 200 | 9.8 | 4.0 | 40.9 | 97.1 | 97.1 | 40.9 | 2.9 |
| Pan | 7.1 | 2.9 | 40.9 | 100.0 | 100.0 | 40.9 | 0.0 |
| Total | 244.3 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 138 |
|---------------|--------------|----------|-------------|------------|-------------|------------|-----|
| | Depth (m) | | 2.29 - 2.74 | | Dry Wt. (g) | | |
| | Soil Wt. (g) | Retained | % Retained | % Retained | Accum. | % Retained | |
| 3/8 | 7.5 | 1.5 | 1.5 | 1.5 | 1.5 | 98.5 | |
| 4 | 14.0 | 2.8 | 2.8 | 4.3 | 4.3 | 95.7 | |
| 10 | 16.0 | 3.2 | 3.2 | 7.6 | 7.6 | 92.4 | |
| 20 | 35.1 | 7.1 | 7.1 | 14.7 | 14.7 | 85.3 | |
| 40 | 177.4 | 35.9 | 35.9 | 50.5 | 50.5 | 49.5 | |
| 60 | 156.1 | 31.6 | 31.6 | 82.1 | 82.1 | 17.9 | |
| 80 | 42.6 | 8.6 | 8.6 | 90.7 | 90.7 | 9.3 | |
| 100 | 14.8 | 3.0 | 3.0 | 93.7 | 93.7 | 6.3 | |
| 200 | 20.7 | 4.2 | 4.2 | 97.9 | 97.9 | 2.1 | |
| Pan | 10.4 | 2.1 | 2.1 | 100.0 | 100.0 | 0.0 | |
| Total | 494.6 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 141 |
|------------|--------------|----------|-------------|------------|-------------|------------|-------|
| | Depth (m) | | 3.66 - 4.11 | | Dry Wt. (g) | | |
| | Soil Wt. (g) | Retained | % Retained | % Retained | Accum. | % Retained | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 3.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 99.3 |
| 10 | 7.3 | 1.5 | 1.5 | 2.2 | 2.2 | 2.2 | 97.8 |
| 20 | 24.8 | 5.0 | 5.0 | 7.2 | 7.2 | 7.2 | 92.8 |
| 40 | 103.7 | 20.9 | 20.9 | 28.1 | 28.1 | 28.1 | 71.9 |
| 60 | 147.4 | 29.7 | 29.7 | 57.8 | 57.8 | 57.8 | 42.2 |
| 80 | 72.8 | 14.7 | 14.7 | 72.5 | 72.5 | 72.5 | 27.5 |
| 100 | 33.7 | 6.8 | 6.8 | 79.3 | 79.3 | 79.3 | 20.7 |
| 200 | 63.0 | 12.7 | 12.7 | 91.9 | 91.9 | 91.9 | 8.1 |
| Pan | 40.0 | 8.1 | 8.1 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | 496.4 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 142 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.7 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 99.9 |
| 10 | 5.9 | 1.2 | 1.2 | 1.3 | 1.3 | 1.3 | 98.7 |
| 20 | 33.0 | 6.6 | 6.6 | 7.9 | 7.9 | 92.1 | 92.1 |
| 40 | 136.2 | 27.2 | 27.2 | 35.1 | 35.1 | 64.9 | 64.9 |
| 60 | 152.4 | 30.5 | 30.5 | 65.6 | 65.6 | 34.4 | 34.4 |
| 80 | 60.4 | 12.1 | 12.1 | 77.7 | 77.7 | 22.3 | 22.3 |
| 100 | 28.3 | 5.7 | 5.7 | 83.3 | 83.3 | 16.7 | 16.7 |
| 200 | 55.4 | 11.1 | 11.1 | 94.4 | 94.4 | 5.6 | 5.6 |
| Pan | 27.9 | | 5.6 | 100.0 | 100.0 | 0.0 | 0.0 |
| Total | 500.2 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 145 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 7.0 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 98.6 |
| 10 | 6.7 | 1.4 | 1.4 | 2.8 | 2.8 | 97.2 | 97.2 |
| 20 | 8.3 | 1.7 | 1.7 | 4.5 | 4.5 | 95.5 | 95.5 |
| 40 | 15.4 | 3.1 | 3.1 | 7.6 | 7.6 | 92.4 | 92.4 |
| 60 | 68.0 | 13.8 | 13.8 | 21.4 | 21.4 | 78.6 | 78.6 |
| 80 | 131.2 | 26.6 | 26.6 | 48.0 | 48.0 | 52.0 | 52.0 |
| 100 | 66.6 | 13.5 | 13.5 | 61.5 | 61.5 | 38.5 | 38.5 |
| 200 | 156.9 | 31.8 | 31.8 | 93.3 | 93.3 | 6.7 | 6.7 |
| Pan | 32.8 | | 6.7 | 100.0 | 100.0 | 0.0 | 0.0 |
| Total | 492.9 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 148 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.4 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 99.9 |
| 40 | 13.5 | 2.7 | 2.7 | 2.8 | 2.8 | 97.2 | 97.2 |
| 60 | 150.6 | 30.2 | 30.2 | 33.0 | 33.0 | 67.0 | 67.0 |
| 80 | 148.7 | 29.9 | 29.9 | 62.9 | 62.9 | 37.1 | 37.1 |
| 100 | 61.1 | 12.3 | 12.3 | 75.2 | 75.2 | 24.8 | 24.8 |
| 200 | 91.4 | 18.4 | 18.4 | 93.5 | 93.5 | 6.5 | 6.5 |
| Pan | 32.2 | | 6.5 | 100.0 | 100.0 | 0.0 | 0.0 |
| Total | 497.9 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 143 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.7 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 99.9 |
| 10 | 3.9 | 0.8 | 0.8 | 0.9 | 0.9 | 99.1 | 99.1 |
| 20 | 22.0 | 4.5 | 4.5 | 5.4 | 5.4 | 94.6 | 94.6 |
| 40 | 77.8 | 15.8 | 15.8 | 21.3 | 21.3 | 78.7 | 78.7 |
| 60 | 88.4 | 18.0 | 18.0 | 39.3 | 39.3 | 60.7 | 60.7 |
| 80 | 58.5 | 11.9 | 11.9 | 51.2 | 51.2 | 48.8 | 48.8 |
| 100 | 36.3 | 7.4 | 7.4 | 58.6 | 58.6 | 41.4 | 41.4 |
| 200 | 122.0 | 24.9 | 24.9 | 83.4 | 83.4 | 16.6 | 16.6 |
| Pan | 81.3 | | 16.6 | 100.0 | 100.0 | 0.0 | 0.0 |
| Total | 490.9 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 146 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.6 | 0.1 | 0.1 | 0.1 | 0.1 | 99.9 | 99.9 |
| 20 | 1.1 | 0.2 | 0.2 | 0.3 | 0.3 | 99.7 | 99.7 |
| 40 | 4.1 | 0.8 | 0.8 | 1.2 | 1.2 | 98.8 | 98.8 |
| 60 | 41.4 | 8.3 | 8.3 | 9.4 | 9.4 | 90.6 | 90.6 |
| 80 | 96.4 | 19.2 | 19.2 | 28.6 | 28.6 | 71.4 | 71.4 |
| 100 | 93.0 | 18.5 | 18.5 | 47.2 | 47.2 | 52.8 | 52.8 |
| 200 | 196.2 | 39.1 | 39.1 | 86.3 | 86.3 | 13.7 | 13.7 |
| Pan | 68.6 | | 13.7 | 100.0 | 100.0 | 0.0 | 0.0 |
| Total | 501.4 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 149 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.6 | 0.1 | 0.1 | 0.1 | 0.1 | 99.9 | 99.9 |
| 40 | 14.4 | 2.9 | 2.9 | 3.0 | 3.0 | 97.0 | 97.0 |
| 60 | 141.7 | 28.4 | 28.4 | 31.4 | 31.4 | 68.6 | 68.6 |
| 80 | 171.0 | 34.3 | 34.3 | 65.8 | 65.8 | 34.2 | 34.2 |
| 100 | 61.8 | 12.4 | 12.4 | 78.2 | 78.2 | 21.8 | 21.8 |
| 200 | 85.7 | 17.2 | 17.2 | 95.3 | 95.3 | 4.7 | 4.7 |
| Pan | 23.2 | | 4.7 | 100.0 | 100.0 | 0.0 | 0.0 |
| Total | 498.4 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 144 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 2.4 | 0.5 | 0.5 | 0.5 | 0.5 | 99.5 | 99.5 |
| 10 | 4.0 | 0.8 | 0.8 | 1.3 | 1.3 | 98.7 | 98.7 |
| 20 | 12.1 | 2.5 | 2.5 | 3.8 | 3.8 | 96.2 | 96.2 |
| 40 | 54.9 | 11.1 | 11.1 | 14.9 | 14.9 | 85.1 | 85.1 |
| 60 | 144.5 | 29.3 | 29.3 | 44.2 | 44.2 | 55.8 | 55.8 |
| 80 | 98.4 | 20.0 | 20.0 | 64.2 | 64.2 | 35.8 | 35.8 |
| 100 | 48.7 | 9.9 | 9.9 | 74.1 | 74.1 | 25.9 | 25.9 |
| 200 | 97.9 | 19.9 | 19.9 | 93.9 | 93.9 | 6.1 | 6.1 |
| Pan | 29.9 | | 6.1 | 100.0 | 100.0 | 0.0 | 0.0 |
| Total | 492.8 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 147 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 1.1 | 0.2 | 0.2 | 0.2 | 0.2 | 99.8 | 99.8 |
| 40 | 4.0 | 0.8 | 0.8 | 1.0 | 1.0 | 99.0 | 99.0 |
| 60 | 26.4 | 5.3 | 5.3 | 6.3 | 6.3 | 93.7 | 93.7 |
| 80 | 92.4 | 18.6 | 18.6 | 24.9 | 24.9 | 75.1 | 75.1 |
| 100 | 65.3 | 13.1 | 13.1 | 38.0 | 38.0 | 62.0 | 62.0 |
| 200 | 234.7 | 47.1 | 47.1 | 85.1 | 85.1 | 14.9 | 14.9 |
| Pan | 74.1 | | 14.9 | 100.0 | 100.0 | 0.0 | 0.0 |
| Total | 498.1 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 150 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.3 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 99.9 |
| 10 | 0.1 | 0.0 | 0.0 | 0.1 | 0.1 | 99.9 | 99.9 |
| 20 | 0.6 | 0.1 | 0.1 | 0.2 | 0.2 | 99.8 | 99.8 |
| 40 | 6.2 | 1.3 | 1.3 | 1.5 | 1.5 | 98.5 | 98.5 |
| 60 | 61.8 | 12.5 | 12.5 | 14.0 | 14.0 | 86.0 | 86.0 |
| 80 | 83.7 | 17.0 | 17.0 | 30.9 | 30.9 | 69.1 | 69.1 |
| 100 | 53.9 | 10.9 | 10.9 | 41.8 | 41.8 | 58.2 | 58.2 |
| 200 | 177.0 | 35.9 | 35.9 | 77.7 | 77.7 | 22.3 | 22.3 |
| Pan | 110.1 | | 22.3 | 100.0 | 100.0 | 0.0 | 0.0 |
| Total | 493.7 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 151 |
|------------|-----------|--------------|-------------|------------|-------------|---------|-------|
| | Depth (m) | Soil Wt. (g) | 8.23 - 8.69 | % Retained | Dry Wt. (g) | Accum. | 493.2 |
| | Retained | % Retained | 0.0 | 0.0 | % Retained | % Finer | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | |
| 20 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | |
| 40 | 1.2 | 0.2 | 0.2 | 0.3 | 0.3 | 99.7 | |
| 60 | 14.7 | 3.0 | 3.0 | 3.2 | 3.2 | 96.8 | |
| 80 | 81.6 | 16.5 | 16.5 | 19.8 | 19.8 | 80.2 | |
| 100 | 69.9 | 14.2 | 14.2 | 34.0 | 34.0 | 66.0 | |
| 200 | 265.6 | 53.9 | 53.9 | 87.8 | 87.8 | 12.2 | |
| Pan | 60.0 | 12.2 | 12.2 | 100.0 | 100.0 | 0.0 | |
| Total | 493.1 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 154 |
|------------|-----------|--------------|--------------|------------|-------------|---------|-------|
| | Depth (m) | Soil Wt. (g) | 9.60 - 10.06 | % Retained | Dry Wt. (g) | Accum. | 492.4 |
| | Retained | % Retained | 0.0 | 0.0 | % Retained | % Finer | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | |
| 10 | 0.3 | 0.1 | 0.1 | 0.1 | 0.1 | 99.9 | |
| 20 | 5.5 | 1.1 | 1.1 | 1.2 | 1.2 | 98.8 | |
| 40 | 176.6 | 35.9 | 35.9 | 37.0 | 37.0 | 63.0 | |
| 60 | 230.4 | 46.8 | 46.8 | 83.8 | 83.8 | 16.2 | |
| 80 | 46.1 | 9.4 | 9.4 | 93.2 | 93.2 | 6.8 | |
| 100 | 10.8 | 2.2 | 2.2 | 95.4 | 95.4 | 4.6 | |
| 200 | 13.5 | 2.7 | 2.7 | 98.1 | 98.1 | 1.9 | |
| Pan | 9.2 | 1.9 | 1.9 | 100.0 | 100.0 | 0.0 | |
| Total | 492.4 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 157 |
|------------|-----------|--------------|---------------|------------|-------------|---------|-------|
| | Depth (m) | Soil Wt. (g) | 10.97 - 11.43 | % Retained | Dry Wt. (g) | Accum. | 347.5 |
| | Retained | % Retained | 0.0 | 0.0 | % Retained | % Finer | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | |
| 10 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | |
| 20 | 5.3 | 1.5 | 1.5 | 1.6 | 1.6 | 98.4 | |
| 40 | 98.2 | 28.3 | 28.3 | 29.8 | 29.8 | 70.2 | |
| 60 | 178.9 | 51.5 | 51.5 | 81.3 | 81.3 | 18.7 | |
| 80 | 42.1 | 12.1 | 12.1 | 93.4 | 93.4 | 6.6 | |
| 100 | 8.0 | 2.3 | 2.3 | 95.7 | 95.7 | 4.3 | |
| 200 | 8.6 | 2.5 | 2.5 | 98.2 | 98.2 | 1.8 | |
| Pan | 6.3 | 1.8 | 1.8 | 100.0 | 100.0 | 0.0 | |
| Total | 347.5 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 152 |
|------------|-----------|--------------|-------------|------------|-------------|---------|-------|
| | Depth (m) | Soil Wt. (g) | 8.69 - 9.14 | % Retained | Dry Wt. (g) | Accum. | 494.2 |
| | Retained | % Retained | 0.0 | 0.0 | % Retained | % Finer | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | |
| 20 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | |
| 40 | 7.3 | 1.5 | 1.5 | 1.5 | 1.5 | 98.5 | |
| 60 | 88.6 | 17.9 | 17.9 | 19.5 | 19.5 | 80.5 | |
| 80 | 134.3 | 27.2 | 27.2 | 46.7 | 46.7 | 53.3 | |
| 100 | 81.3 | 16.5 | 16.5 | 63.1 | 63.1 | 36.9 | |
| 200 | 140.9 | 28.5 | 28.5 | 91.7 | 91.7 | 8.3 | |
| Pan | 41.2 | 8.3 | 8.3 | 100.0 | 100.0 | 0.0 | |
| Total | 493.8 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 155 |
|------------|-----------|--------------|---------------|------------|-------------|---------|-------|
| | Depth (m) | Soil Wt. (g) | 10.06 - 10.52 | % Retained | Dry Wt. (g) | Accum. | 494.3 |
| | Retained | % Retained | 0.0 | 0.0 | % Retained | % Finer | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | |
| 4 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | |
| 10 | 1.1 | 0.2 | 0.2 | 0.3 | 0.3 | 99.7 | |
| 20 | 18.1 | 3.7 | 3.7 | 3.9 | 3.9 | 96.1 | |
| 40 | 191.8 | 38.8 | 38.8 | 42.7 | 42.7 | 57.3 | |
| 60 | 211.7 | 42.8 | 42.8 | 85.6 | 85.6 | 14.4 | |
| 80 | 35.0 | 7.1 | 7.1 | 92.7 | 92.7 | 7.3 | |
| 100 | 9.8 | 2.0 | 2.0 | 94.7 | 94.7 | 5.3 | |
| 200 | 14.0 | 2.8 | 2.8 | 97.5 | 97.5 | 2.5 | |
| Pan | 12.4 | 2.5 | 2.5 | 100.0 | 100.0 | 0.0 | |
| Total | 494.1 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 158 |
|------------|-----------|--------------|---------------|------------|-------------|----------------------|---------|
| | Depth (m) | Soil Wt. (g) | 11.43 - 11.89 | % Retained | Dry Wt. (g) | Accum. % Retained | % Finer |
| | | Retained | | | | | |
| 3/8 | 4.1 | 4.1 | 1.0 | | 1.0 | | 99.0 |
| 4 | 1.2 | 1.2 | 0.3 | | 1.3 | | 98.7 |
| 10 | 3.6 | 3.6 | 0.9 | | 2.2 | | 97.8 |
| 20 | 19.8 | 19.8 | 4.9 | | 7.1 | | 92.9 |
| 40 | 151.7 | 151.7 | 37.7 | | 44.8 | | 55.2 |
| 60 | 150.3 | 150.3 | 37.3 | | 82.2 | | 17.8 |
| 80 | 26.8 | 26.8 | 6.7 | | 88.8 | | 11.2 |
| 100 | 8.3 | 8.3 | 2.1 | | 90.9 | | 9.1 |
| 200 | 17.7 | 17.7 | 4.4 | | 95.3 | | 4.7 |
| Pan | 19.0 | 19.0 | 4.7 | | 100.0 | | 0.0 |
| Total | 402.5 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 153 |
|---------------|-----------|--------------|-------------|------------|-------------|---------|-------|
| | Depth (m) | Soil Wt. (g) | 9.14 - 9.60 | % Retained | Dry Wt. (g) | Accum. | 494.1 |
| | Retained | % Retained | 0.0 | 0.0 | 0.0 | % Finer | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | |
| 10 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | |
| 20 | 1.9 | 0.4 | 0.4 | 0.4 | 0.4 | 99.6 | |
| 40 | 42.1 | 8.5 | 8.5 | 9.0 | 9.0 | 91.0 | |
| 60 | 172.6 | 35.0 | 35.0 | 43.9 | 43.9 | 56.1 | |
| 80 | 93.5 | 18.9 | 18.9 | 62.8 | 62.8 | 37.2 | |
| 100 | 34.4 | 7.0 | 7.0 | 69.8 | 69.8 | 30.2 | |
| 200 | 101.4 | 20.5 | 20.5 | 90.3 | 90.3 | 9.7 | |
| Pan | 47.7 | 9.7 | 9.7 | 100.0 | 100.0 | 0.0 | |
| Total | 493.8 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 156 |
|---------------|-----------|--------------|---------------|------------|-------------|------------|---------|
| | Depth (m) | Soil Wt. (g) | 10.52 - 10.97 | % Retained | Dry Wt. (g) | Accum. | 498.6 |
| | | Retained | | % Retained | | % Retained | % Finer |
| 3/8 | 6.5 | 6.5 | 1.3 | 1.3 | 1.3 | 1.3 | 98.7 |
| 4 | 4.3 | 4.3 | 0.9 | 0.9 | 2.2 | 2.2 | 97.8 |
| 10 | 10.7 | 10.7 | 2.1 | 2.1 | 4.3 | 4.3 | 95.7 |
| 20 | 29.1 | 29.1 | 5.8 | 5.8 | 10.2 | 10.2 | 89.8 |
| 40 | 191.0 | 191.0 | 38.3 | 38.3 | 48.5 | 48.5 | 51.5 |
| 60 | 191.7 | 191.7 | 38.5 | 38.5 | 87.0 | 87.0 | 13.0 |
| 80 | 29.4 | 29.4 | 5.9 | 5.9 | 92.9 | 92.9 | 7.1 |
| 100 | 7.2 | 7.2 | 1.4 | 1.4 | 94.3 | 94.3 | 5.7 |
| 200 | 12.0 | 12.0 | 2.4 | 2.4 | 96.7 | 96.7 | 3.3 |
| Pan | 16.4 | 16.4 | 3.3 | 3.3 | 100.0 | 100.0 | 0.0 |
| Total | | 498.3 | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 159 |
|------------|-----------|--------------|---------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | 11.89 - 12.34 | % Retained | Dry Wt. (g) | Accum. | 269.3 |
| | | Retained | | | | | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | |
| 10 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | |
| 20 | 11.4 | 4.2 | 4.2 | 4.3 | 4.3 | 95.7 | |
| 40 | 129.1 | 48.0 | 48.0 | 52.2 | 52.2 | 47.8 | |
| 60 | 104.8 | 38.9 | 38.9 | 91.2 | 91.2 | 8.8 | |
| 80 | 14.8 | 5.5 | 5.5 | 96.7 | 96.7 | 3.3 | |
| 100 | 3.0 | 1.1 | 1.1 | 97.8 | 97.8 | 2.2 | |
| 200 | 3.8 | 1.4 | 1.4 | 99.2 | 99.2 | 0.8 | |
| Pan | 2.2 | 0.8 | 0.8 | 100.0 | 100.0 | 0.0 | |
| Total | 269.2 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 160 |
|------------|-----------|--------------|---------------|---------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | 12.34 - 12.80 | 13.72 - 14.17 | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 315.6 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 13.3 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 95.8 |
| 40 | 156.5 | 49.6 | 49.6 | 53.9 | 53.9 | 53.9 | 46.1 |
| 60 | 119.0 | 37.7 | 37.7 | 91.6 | 91.6 | 91.6 | 8.4 |
| 80 | 17.1 | 5.4 | 5.4 | 97.0 | 97.0 | 97.0 | 3.0 |
| 100 | 3.4 | 1.1 | 1.1 | 98.1 | 98.1 | 98.1 | 1.9 |
| 200 | 4.1 | 1.3 | 1.3 | 99.4 | 99.4 | 99.4 | 0.6 |
| Pan | 1.9 | 0.6 | 0.6 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | 315.4 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 161 |
|------------|-----------|--------------|---------------|---------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | 12.80 - 13.26 | 14.63 - 15.09 | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 226.8 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 4.7 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 97.9 |
| 40 | 83.3 | 36.8 | 36.8 | 38.9 | 38.9 | 38.9 | 61.1 |
| 60 | 104.7 | 46.2 | 46.2 | 85.1 | 85.1 | 85.1 | 14.9 |
| 80 | 20.8 | 9.2 | 9.2 | 94.3 | 94.3 | 94.3 | 5.7 |
| 100 | 4.4 | 1.9 | 1.9 | 96.2 | 96.2 | 96.2 | 3.8 |
| 200 | 5.3 | 2.3 | 2.3 | 98.6 | 98.6 | 98.6 | 1.4 |
| Pan | 3.2 | 1.4 | 1.4 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | 226.5 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 162 |
|------------|-----------|--------------|---------------|---------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | 13.26 - 13.72 | 14.63 - 15.09 | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 375.1 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 9.7 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 97.4 |
| 40 | 136.7 | 36.5 | 36.5 | 39.1 | 39.1 | 39.1 | 60.9 |
| 60 | 164.6 | 43.9 | 43.9 | 83.0 | 83.0 | 83.0 | 17.0 |
| 80 | 35.5 | 9.5 | 9.5 | 92.5 | 92.5 | 92.5 | 7.5 |
| 100 | 8.9 | 2.4 | 2.4 | 94.8 | 94.8 | 94.8 | 5.2 |
| 200 | 12.2 | 3.3 | 3.3 | 98.1 | 98.1 | 98.1 | 1.9 |
| Pan | 7.1 | 1.9 | 1.9 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | 374.7 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 163 |
|------------|-----------|--------------|---------------|---------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | 13.72 - 14.17 | 15.09 - 15.54 | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 260.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 3.0 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 98.8 |
| 40 | 78.0 | 30.0 | 30.0 | 31.2 | 31.2 | 31.2 | 68.8 |
| 60 | 132.1 | 50.8 | 50.8 | 82.0 | 82.0 | 82.0 | 18.0 |
| 80 | 29.1 | 11.2 | 11.2 | 93.2 | 93.2 | 93.2 | 6.8 |
| 100 | 6.3 | 2.4 | 2.4 | 95.6 | 95.6 | 95.6 | 4.4 |
| 200 | 7.2 | 2.8 | 2.8 | 98.3 | 98.3 | 98.3 | 1.7 |
| Pan | 4.3 | 1.7 | 1.7 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | 260.0 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 164 |
|------------|-----------|--------------|---------------|---------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | 14.17 - 14.63 | 15.54 - 16.00 | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 345.7 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 6.0 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 98.3 |
| 40 | 111.4 | 32.3 | 32.3 | 34.0 | 34.0 | 34.0 | 66.0 |
| 60 | 152.0 | 44.0 | 44.0 | 78.0 | 78.0 | 78.0 | 22.0 |
| 80 | 35.9 | 10.4 | 10.4 | 88.4 | 88.4 | 88.4 | 11.6 |
| 100 | 9.6 | 2.8 | 2.8 | 91.2 | 91.2 | 91.2 | 8.8 |
| 200 | 16.6 | 4.8 | 4.8 | 96.0 | 96.0 | 96.0 | 4.0 |
| Pan | 13.8 | 4.0 | 4.0 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | 345.3 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 165 |
|------------|-----------|--------------|---------------|---------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | 14.63 - 15.09 | 15.54 - 16.00 | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458.4 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 8.2 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 98.2 |
| 40 | 151.1 | 33.0 | 33.0 | 34.8 | 34.8 | 34.8 | 65.2 |
| 60 | 223.5 | 48.8 | 48.8 | 83.6 | 83.6 | 83.6 | 16.4 |
| 80 | 45.5 | 9.9 | 9.9 | 93.5 | 93.5 | 93.5 | 6.5 |
| 100 | 10.2 | 2.2 | 2.2 | 95.7 | 95.7 | 95.7 | 4.3 |
| 200 | 11.4 | 2.5 | 2.5 | 98.2 | 98.2 | 98.2 | 1.8 |
| Pan | 8.2 | 1.8 | 1.8 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | 458.1 | | | | | | |

| Sieve Size | Boring | | SPK1 | | Sample | | 166 |
|------------|-----------|--------------|---------------|---------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | 15.09 - 15.54 | 16.00 - 16.46 | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 499.3 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 1.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 99.7 |
| 20 | 24.3 | 4.9 | 4.9 | 5.1 | 5.1 | 5.1 | 94.9 |
| 40 | 175.3 | 35.1 | 35.1 | 40.2 | 40.2 | 40.2 | 59.8 |
| 60 | 217.0 | 43.5 | 43.5 | 83.7 | 83.7 | 83.7 | 16.3 |
| 80 | 51.2 | 10.3 | 10.3 | 94.0 | 94.0 | 94.0 | 6.0 |
| 100 | 11.5 | 2.3 | 2.3 | 96.3 | 96.3 | 96.3 | 3.7 |
| 200 | 12.6 | 2.5 | 2.5 | 98.8 | 98.8 | 98.8 | 1.2 |
| Pan | 6.1 | 1.2 | 1.2 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | 499.3 | | | | | | |

| Sieve Size | Boring | | SPK2 | | Sample | | 3 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 263.4 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 2.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 9.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 23.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 40 | 85.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 60 | 105.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 100 | 42.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 200 | 18.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| Pan | 12.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| Total | 299.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |

| Sieve Size | Boring | | SPK2 | | Sample | | 2 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 277.5 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 8.9 | 4.4 | 1.6 | 1.6 | 1.6 | 1.6 | 98.4 |
| 10 | 9.3 | 3.4 | 3.2 | 4.8 | 4.8 | 95.2 | 91.8 |
| 20 | 29.8 | 10.8 | 18.9 | 81.1 | 81.1 | 81.1 | 81.1 |
| 40 | 76.5 | 40.7 | 46.5 | 53.5 | 53.5 | 53.5 | 53.5 |
| 60 | 62.8 | 27.7 | 69.2 | 30.8 | 30.8 | 30.8 | 30.8 |
| 100 | 48.3 | 17.4 | 86.6 | 13.4 | 13.4 | 13.4 | 13.4 |
| 200 | 27.8 | 10.0 | 96.6 | 3.4 | 3.4 | 3.4 | 3.4 |
| Pan | 9.3 | 3.4 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total | 277.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

| Sieve Size | Boring | | SPK2 | | Sample | | 1 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 299.9 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 2.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 9.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 23.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 40 | 85.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 60 | 105.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 100 | 42.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 200 | 18.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| Pan | 12.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| Total | 299.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |

| Sieve Size | Boring | | SPK2 | | Sample | | 6 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 82.1 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 99.8 |
| 10 | 1.9 | 0.9 | 2.3 | 2.6 | 2.6 | 2.6 | 97.4 |
| 20 | 6.9 | 8.4 | 8.4 | 11.0 | 11.0 | 11.0 | 89.0 |
| 40 | 20.8 | 25.5 | 25.5 | 36.5 | 36.5 | 36.5 | 63.5 |
| 60 | 22.2 | 27.2 | 27.2 | 63.6 | 63.6 | 63.6 | 36.4 |
| 100 | 17.1 | 20.9 | 20.9 | 84.6 | 84.6 | 84.6 | 15.4 |
| 200 | 9.2 | 11.3 | 11.3 | 95.8 | 95.8 | 95.8 | 4.2 |
| Pan | 3.4 | 4.2 | 4.2 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | 81.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

| Sieve Size | Boring | | SPK2 | | Sample | | 5 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 34.4 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.6 | 1.7 | 1.7 | 98.3 | 98.3 | 98.3 | 98.3 |
| 20 | 3.8 | 11.0 | 12.8 | 87.2 | 87.2 | 87.2 | 87.2 |
| 40 | 10.7 | 31.1 | 43.9 | 56.1 | 56.1 | 56.1 | 56.1 |
| 60 | 9.5 | 27.6 | 71.5 | 28.5 | 28.5 | 28.5 | 28.5 |
| 100 | 5.7 | 16.6 | 88.1 | 11.9 | 11.9 | 11.9 | 11.9 |
| 200 | 2.7 | 7.8 | 95.9 | 4.1 | 4.1 | 4.1 | 4.1 |
| Pan | 1.4 | 4.1 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total | 34.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

| Sieve Size | Boring | | SPK2 | | Sample | | 4 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 32.1 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.6 | 1.9 | 1.9 | 98.1 | 98.1 | 98.1 | 98.1 |
| 10 | 0.5 | 1.6 | 3.4 | 96.6 | 96.6 | 96.6 | 96.6 |
| 20 | 2.7 | 8.4 | 11.8 | 88.2 | 88.2 | 88.2 | 88.2 |
| 40 | 9.1 | 28.3 | 40.2 | 59.8 | 59.8 | 59.8 | 59.8 |
| 60 | 9.7 | 30.2 | 70.4 | 29.6 | 29.6 | 29.6 | 29.6 |
| 100 | 5.4 | 16.8 | 87.2 | 12.8 | 12.8 | 12.8 | 12.8 |
| 200 | 2.6 | 8.1 | 95.3 | 4.7 | 4.7 | 4.7 | 4.7 |
| Pan | 1.5 | 4.7 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total | 32.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

| Sieve Size | Boring | | SPK2 | | Sample | | 9 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 415.6 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 1.0 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 99.8 |
| 10 | 1.8 | 0.4 | 0.4 | 0.7 | 0.7 | 0.7 | 99.3 |
| 20 | 2.8 | 0.7 | 0.7 | 1.3 | 1.3 | 1.3 | 98.7 |
| 40 | 33.5 | 8.1 | 8.1 | 9.4 | 9.4 | 9.4 | 90.6 |
| 60 | 195.0 | 46.9 | 46.9 | 56.3 | 56.3 | 56.3 | 43.7 |
| 100 | 143.4 | 34.5 | 34.5 | 90.8 | 90.8 | 90.8 | 9.2 |
| 200 | 32.1 | 7.7 | 7.7 | 98.6 | 98.6 | 98.6 | 1.4 |
| Pan | 6.0 | 1.4 | 1.4 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | 415.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

| Sieve Size | Boring | | SPK2 | | Sample | | 8 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 428.5 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 1.7 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 99.6 |
| 10 | 8.6 | 2.0 | 2.4 | 97.6 | 97.6 | 97.6 | 97.6 |
| 20 | 15.6 | 3.6 | 6.0 | 94.0 | 94.0 | 94.0 | 94.0 |
| 40 | 42.6 | 9.9 | 16.0 | 84.0 | 84.0 | 84.0 | 84.0 |
| 60 | 92.9 | 21.7 | 37.7 | 62.3 | 62.3 | 62.3 | 62.3 |
| 100 | 92.6 | 21.6 | 59.3 | 40.7 | 40.7 | 40.7 | 40.7 |
| 200 | 157.9 | 36.8 | 96.1 | 3.9 | 3.9 | 3.9 | 3.9 |
| Pan | 16.6 | 3.9 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total | 428.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

| Sieve Size | Boring | | SPK2 | | Sample | | 7 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 316.5 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.3 | 0.1 | 0.1 | 99.9 | 99.9 | 99.9 | 99.9 |
| 10 | 2.5 | 0.8 | 0.9 | 99.1 | 99.1 | 99.1 | 99.1 |
| 20 | 19.1 | 6.0 | 6.9 | 93.1 | 93.1 | 93.1 | 93.1 |
| 40 | 66.3 | 21.0 | 27.9 | 72.1 | 72.1 | 72.1 | 72.1 |
| 60 | 56.6 | 17.9 | 45.8 | 54.2 | 54.2 | 54.2 | 54.2 |
| 100 | 54.2 | 17.1 | 62.9 | 37.1 | 37.1 | 37.1 | 37.1 |
| 200 | 90.4 | 28.6 | 91.5 | 8.5 | 8.5 | 8.5 | 8.5 |
| Pan | 27.0 | 8.5 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total | 316.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

| Sieve Size | Boring | | SPK2 | | Sample | | 10 | |
|------------|-----------|--------------|------------|------------|-------------|--------|------------|---------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | % Retained | % Finer |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 1.0 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 99.7 | 99.7 |
| 20 | 4.6 | 1.2 | 1.4 | 1.4 | 1.4 | 1.4 | 98.6 | 98.6 |
| 40 | 36.8 | 9.3 | 10.7 | 10.7 | 10.7 | 10.7 | 89.3 | 89.3 |
| 60 | 91.8 | 23.2 | 33.8 | 33.8 | 33.8 | 33.8 | 66.2 | 66.2 |
| 100 | 132.1 | 33.3 | 67.2 | 67.2 | 67.2 | 67.2 | 32.8 | 32.8 |
| 200 | 104.8 | 26.4 | 93.6 | 93.6 | 93.6 | 93.6 | 6.4 | 6.4 |
| Pan | 25.4 | 6.4 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 | 0.0 |
| Total | 396.5 | | | | | | | |

| Sieve Size | Boring | | SPK2 | | Sample | | 13 | |
|------------|-----------|--------------|------------|------------|-------------|--------|------------|---------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | % Retained | % Finer |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 40 | 0.9 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 99.7 | 99.7 |
| 60 | 34.7 | 8.6 | 8.8 | 8.8 | 8.8 | 8.8 | 91.2 | 91.2 |
| 100 | 119.3 | 29.4 | 38.2 | 38.2 | 38.2 | 38.2 | 61.8 | 61.8 |
| 200 | 177.1 | 43.7 | 81.9 | 81.9 | 81.9 | 81.9 | 18.1 | 18.1 |
| Pan | 73.4 | 18.1 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 | 0.0 |
| Total | 405.6 | | | | | | | |

| Sieve Size | Boring | | SPK2 | | Sample | | 16 | |
|------------|-----------|--------------|------------|------------|-------------|--------|------------|---------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | % Retained | % Finer |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.3 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 99.9 | 99.9 |
| 40 | 19.7 | 5.5 | 5.6 | 5.6 | 5.6 | 5.6 | 94.4 | 94.4 |
| 60 | 163.4 | 45.6 | 51.2 | 51.2 | 51.2 | 51.2 | 48.8 | 48.8 |
| 100 | 135.5 | 37.8 | 89.0 | 89.0 | 89.0 | 89.0 | 11.0 | 11.0 |
| 200 | 31.9 | 8.9 | 97.9 | 97.9 | 97.9 | 97.9 | 2.1 | 2.1 |
| Pan | 7.5 | 2.1 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 | 0.0 |
| Total | 358.3 | | | | | | | |

| Sieve Size | Boring | | SPK2 | | Sample | | 11 | |
|------------|-----------|--------------|------------|------------|-------------|--------|------------|---------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | % Retained | % Finer |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 3.7 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 99.1 | 99.1 |
| 20 | 6.3 | 1.5 | 2.3 | 2.3 | 2.3 | 2.3 | 97.7 | 97.7 |
| 40 | 21.6 | 5.1 | 7.4 | 7.4 | 7.4 | 7.4 | 92.6 | 92.6 |
| 60 | 119.7 | 28.0 | 35.4 | 35.4 | 35.4 | 35.4 | 64.6 | 64.6 |
| 100 | 183.6 | 43.0 | 78.4 | 78.4 | 78.4 | 78.4 | 21.6 | 21.6 |
| 200 | 78.5 | 18.4 | 96.8 | 96.8 | 96.8 | 96.8 | 3.2 | 3.2 |
| Pan | 13.5 | 3.2 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 | 0.0 |
| Total | 426.9 | | | | | | | |

| Sieve Size | Boring | | SPK2 | | Sample | | 14 | |
|------------|-----------|--------------|------------|------------|-------------|--------|------------|---------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | % Retained | % Finer |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 40 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 99.9 | 99.9 |
| 60 | 18.9 | 5.3 | 5.4 | 5.4 | 5.4 | 5.4 | 94.6 | 94.6 |
| 100 | 101.6 | 28.3 | 33.6 | 33.6 | 33.6 | 33.6 | 66.4 | 66.4 |
| 200 | 168.4 | 46.9 | 80.5 | 80.5 | 80.5 | 80.5 | 19.5 | 19.5 |
| Pan | 70.0 | 19.5 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 | 0.0 |
| Total | 359.3 | | | | | | | |

| Sieve Size | Boring | | SPK2 | | Sample | | 17 | |
|------------|-----------|--------------|------------|------------|-------------|--------|------------|---------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | % Retained | % Finer |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.4 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 99.9 | 99.9 |
| 40 | 0.6 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 99.7 | 99.7 |
| 60 | 3.0 | 0.8 | 1.1 | 1.1 | 1.1 | 1.1 | 98.9 | 98.9 |
| 100 | 91.5 | 24.2 | 25.2 | 25.2 | 25.2 | 25.2 | 74.8 | 74.8 |
| 200 | 198.4 | 52.4 | 77.6 | 77.6 | 77.6 | 77.6 | 22.4 | 22.4 |
| Pan | 84.7 | 22.4 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 | 0.0 |
| Total | 378.6 | | | | | | | |

| Sieve Size | Boring | | SPK2 | | Sample | | 12 | |
|------------|-----------|--------------|------------|------------|-------------|--------|------------|---------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | % Retained | % Finer |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 40 | 0.6 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 99.8 | 99.8 |
| 60 | 27.1 | 6.7 | 7.0 | 7.0 | 7.0 | 7.0 | 93.0 | 93.0 |
| 100 | 180.5 | 44.9 | 51.9 | 51.9 | 51.9 | 51.9 | 48.1 | 48.1 |
| 200 | 165.5 | 41.2 | 93.1 | 93.1 | 93.1 | 93.1 | 6.9 | 6.9 |
| Pan | 27.7 | 6.9 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 | 0.0 |
| Total | 401.8 | | | | | | | |

| Sieve Size | Boring | | SPK2 | | Sample | | 15 | |
|------------|-----------|--------------|------------|------------|-------------|--------|------------|---------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | % Retained | % Finer |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.5 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 99.8 | 99.8 |
| 20 | 1.8 | 0.5 | 0.6 | 0.6 | 0.6 | 0.6 | 99.4 | 99.4 |
| 40 | 9.7 | 2.6 | 3.2 | 3.2 | 3.2 | 3.2 | 96.8 | 96.8 |
| 60 | 61.9 | 16.3 | 19.5 | 19.5 | 19.5 | 19.5 | 80.5 | 80.5 |
| 100 | 164.7 | 43.4 | 62.8 | 62.8 | 62.8 | 62.8 | 37.2 | 37.2 |
| 200 | 114.0 | 30.0 | 92.8 | 92.8 | 92.8 | 92.8 | 7.2 | 7.2 |
| Pan | 27.2 | 7.2 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 | 0.0 |
| Total | 379.9 | | | | | | | |

| Sieve Size | Boring | | SPK2 | | Sample | | 18 | |
|------------|-----------|--------------|------------|------------|-------------|--------|------------|---------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | % Retained | % Finer |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.4 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 99.9 | 99.9 |
| 40 | 2.1 | 0.5 | 0.6 | 0.6 | 0.6 | 0.6 | 99.4 | 99.4 |
| 60 | 39.6 | 9.6 | 10.2 | 10.2 | 10.2 | 10.2 | 89.8 | 89.8 |
| 100 | 162.1 | 39.3 | 49.5 | 49.5 | 49.5 | 49.5 | 50.5 | 50.5 |
| 200 | 134.1 | 32.5 | 82.1 | 82.1 | 82.1 | 82.1 | 17.9 | 17.9 |
| Pan | 74.0 | 17.9 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 | 0.0 |
| Total | 412.4 | | | | | | | |

| Sieve Size | Boring | | SPK2 | | Sample | |
|------------|-----------|--------------|-------------|------------|-------------|-------|
| | Depth (m) | Soil Wt. (g) | 9.14 - 9.60 | % Retained | Dry Wt. (g) | 21 |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 483.2 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.4 | 0.1 | 0.1 | 0.1 | 99.9 |
| 20 | 1.0 | 1.0 | 0.2 | 0.2 | 0.3 | 99.7 |
| 40 | 15.1 | 15.1 | 3.1 | 3.1 | 3.4 | 96.6 |
| 60 | 155.4 | 155.4 | 32.2 | 32.2 | 35.6 | 64.4 |
| 100 | 186.4 | 186.4 | 38.6 | 38.6 | 74.2 | 25.8 |
| 200 | 91.6 | 91.6 | 19.0 | 19.0 | 93.2 | 6.8 |
| Pan | 32.8 | 32.8 | 6.8 | 6.8 | 100.0 | 0.0 |
| Total | 482.7 | 482.7 | | | | |

| Sieve Size | Boring | | SPK2 | | Sample | |
|------------|-----------|--------------|---------------|------------|-------------|-------|
| | Depth (m) | Soil Wt. (g) | 10.52 - 10.97 | % Retained | Dry Wt. (g) | 24 |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 519.4 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 8.7 | 8.7 | 1.7 | 1.7 | 1.7 | 98.3 |
| 10 | 25.0 | 25.0 | 4.8 | 4.8 | 6.5 | 93.5 |
| 20 | 70.6 | 70.6 | 13.6 | 13.6 | 20.1 | 79.9 |
| 40 | 197.7 | 197.7 | 38.1 | 38.1 | 58.1 | 41.9 |
| 60 | 168.2 | 168.2 | 32.4 | 32.4 | 90.5 | 9.5 |
| 100 | 27.9 | 27.9 | 5.4 | 5.4 | 95.9 | 4.1 |
| 200 | 10.2 | 10.2 | 2.0 | 2.0 | 97.9 | 2.1 |
| Pan | 11.1 | 11.1 | 2.1 | 2.1 | 100.0 | 0.0 |
| Total | 519.4 | 519.4 | | | | |

| Sieve Size | Boring | | SPK2 | | Sample | |
|------------|-----------|--------------|---------------|------------|-------------|-------|
| | Depth (m) | Soil Wt. (g) | 11.89 - 12.34 | % Retained | Dry Wt. (g) | 27 |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 533.3 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.4 | 0.4 | 0.1 | 0.1 | 0.1 | 99.9 |
| 20 | 8.1 | 8.1 | 1.5 | 1.5 | 1.6 | 98.4 |
| 40 | 238.6 | 238.6 | 44.7 | 44.7 | 46.3 | 53.7 |
| 60 | 230.6 | 230.6 | 43.2 | 43.2 | 89.6 | 10.4 |
| 100 | 44.7 | 44.7 | 8.4 | 8.4 | 98.0 | 2.0 |
| 200 | 9.0 | 9.0 | 1.7 | 1.7 | 99.6 | 0.4 |
| Pan | 1.9 | 1.9 | 0.4 | 0.4 | 100.0 | 0.0 |
| Total | 533.3 | 533.3 | | | | |

| Sieve Size | Boring | | SPK2 | | Sample | |
|------------|-----------|--------------|-------------|------------|-------------|-------|
| | Depth (m) | Soil Wt. (g) | 8.69 - 9.14 | % Retained | Dry Wt. (g) | 20 |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 498.7 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.2 | 0.2 | 0.0 | 0.0 | 0.0 | 100.0 |
| 40 | 10.6 | 10.6 | 2.1 | 2.1 | 2.2 | 97.8 |
| 60 | 149.1 | 149.1 | 29.9 | 29.9 | 32.0 | 68.0 |
| 100 | 217.6 | 217.6 | 43.6 | 43.6 | 75.7 | 24.3 |
| 200 | 102.1 | 102.1 | 20.5 | 20.5 | 96.1 | 3.9 |
| Pan | 19.4 | 19.4 | 3.9 | 3.9 | 100.0 | 0.0 |
| Total | 499.0 | 499.0 | | | | |

| Sieve Size | Boring | | SPK2 | | Sample | |
|------------|-----------|--------------|---------------|------------|-------------|-------|
| | Depth (m) | Soil Wt. (g) | 10.06 - 10.52 | % Retained | Dry Wt. (g) | 23 |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 406.2 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 8.4 | 8.4 | 2.1 | 2.1 | 2.1 | 97.9 |
| 40 | 169.7 | 169.7 | 41.8 | 41.8 | 43.9 | 56.1 |
| 60 | 183.2 | 183.2 | 45.1 | 45.1 | 89.0 | 11.0 |
| 100 | 31.1 | 31.1 | 7.7 | 7.7 | 96.6 | 3.4 |
| 200 | 7.6 | 7.6 | 1.9 | 1.9 | 98.5 | 1.5 |
| Pan | 6.1 | 6.1 | 1.5 | 1.5 | 100.0 | 0.0 |
| Total | 406.2 | 406.2 | | | | |

| Sieve Size | Boring | | SPK2 | | Sample | |
|------------|-----------|--------------|---------------|------------|-------------|-------|
| | Depth (m) | Soil Wt. (g) | 11.43 - 11.89 | % Retained | Dry Wt. (g) | 26 |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 464.2 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 7.4 | 7.4 | 1.6 | 1.6 | 1.6 | 98.4 |
| 40 | 190.9 | 190.9 | 41.1 | 41.1 | 42.7 | 57.3 |
| 60 | 208.2 | 208.2 | 44.9 | 44.9 | 87.6 | 12.4 |
| 100 | 41.4 | 41.4 | 8.9 | 8.9 | 96.5 | 3.5 |
| 200 | 9.3 | 9.3 | 2.0 | 2.0 | 98.5 | 1.5 |
| Pan | 7.0 | 7.0 | 1.5 | 1.5 | 100.0 | 0.0 |
| Total | 464.2 | 464.2 | | | | |

| Sieve Size | Boring | | SPK2 | | Sample | |
|------------|-----------|--------------|-------------|------------|-------------|-------|
| | Depth (m) | Soil Wt. (g) | 8.23 - 8.69 | % Retained | Dry Wt. (g) | 19 |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 467.5 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 100.0 |
| 40 | 0.4 | 0.4 | 0.1 | 0.1 | 0.1 | 99.9 |
| 60 | 27.2 | 27.2 | 5.8 | 5.8 | 5.9 | 94.1 |
| 100 | 150.6 | 150.6 | 32.2 | 32.2 | 38.2 | 61.8 |
| 200 | 230.4 | 230.4 | 49.3 | 49.3 | 87.5 | 12.5 |
| Pan | 58.6 | 58.6 | 12.5 | 12.5 | 100.0 | 0.0 |
| Total | 467.3 | 467.3 | | | | |

| Sieve Size | Boring | | SPK2 | | Sample | |
|------------|-----------|--------------|--------------|------------|-------------|-------|
| | Depth (m) | Soil Wt. (g) | 9.60 - 10.06 | % Retained | Dry Wt. (g) | 22 |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 496.2 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.7 | 0.7 | 0.1 | 0.1 | 0.1 | 99.9 |
| 10 | 1.1 | 1.1 | 0.2 | 0.2 | 0.4 | 99.6 |
| 20 | 24.9 | 24.9 | 5.0 | 5.0 | 5.4 | 94.6 |
| 40 | 182.5 | 182.5 | 36.8 | 36.8 | 42.2 | 57.8 |
| 60 | 203.9 | 203.9 | 41.1 | 41.1 | 83.3 | 16.7 |
| 100 | 57.2 | 57.2 | 11.5 | 11.5 | 94.8 | 5.2 |
| 200 | 16.6 | 16.6 | 3.3 | 3.3 | 98.1 | 1.9 |
| Pan | 9.3 | 9.3 | 1.9 | 1.9 | 100.0 | 0.0 |
| Total | 496.2 | 496.2 | | | | |

| Sieve Size | Boring | | SPK2 | | Sample | |
|------------|-----------|--------------|---------------|------------|-------------|-------|
| | Depth (m) | Soil Wt. (g) | 10.97 - 11.43 | % Retained | Dry Wt. (g) | 25 |
| 3/4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 493.4 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 4.2 | 4.2 | 0.9 | 0.9 | 0.9 | 99.1 |
| 40 | 138.1 | 138.1 | 28.0 | 28.0 | 28.9 | 71.1 |
| 60 | 273.3 | 273.3 | 55.4 | 55.4 | 84.3 | 15.7 |
| 100 | 60.2 | 60.2 | 12.2 | 12.2 | 96.5 | 3.5 |
| 200 | 10.5 | 10.5 | 2.1 | 2.1 | 98.6 | 1.4 |
| Pan | 6.8 | 6.8 | 1.4 | 1.4 | 100.0 | 0.0 |
| Total | 493.1 | 493.1 | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | |
|------------|-----------|--------------|------------|------------|-------------|--------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. |
| 3/8 | 18.1 | 18.1 | 6.6 | 6.6 | 275.7 | 275.7 |
| 4 | 6.6 | 6.6 | 2.4 | 2.4 | 9.0 | 9.0 |
| 10 | 11.2 | 11.2 | 4.1 | 4.1 | 13.0 | 13.0 |
| 20 | 26.5 | 26.5 | 9.6 | 9.6 | 22.6 | 22.6 |
| 40 | 76.9 | 76.9 | 27.9 | 27.9 | 50.5 | 50.5 |
| 60 | 72.5 | 72.5 | 26.3 | 26.3 | 76.8 | 76.8 |
| 80 | 26.3 | 26.3 | 9.5 | 9.5 | 86.4 | 86.4 |
| 100 | 9.9 | 9.9 | 3.6 | 3.6 | 90.0 | 90.0 |
| 200 | 18.4 | 18.4 | 6.7 | 6.7 | 96.6 | 96.6 |
| Pan | 9.3 | 9.3 | 3.4 | 3.4 | 100.0 | 100.0 |
| Total | 275.7 | 275.7 | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | |
|------------|-----------|--------------|------------|------------|-------------|--------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 300.5 | 300.5 |
| 4 | 2.7 | 2.7 | 0.9 | 0.9 | 0.9 | 0.9 |
| 10 | 19.9 | 19.9 | 6.6 | 6.6 | 7.5 | 7.5 |
| 20 | 37.8 | 37.8 | 12.6 | 12.6 | 20.1 | 20.1 |
| 40 | 80.6 | 80.6 | 26.8 | 26.8 | 46.9 | 46.9 |
| 60 | 77.2 | 77.2 | 25.7 | 25.7 | 72.6 | 72.6 |
| 80 | 31.9 | 31.9 | 10.6 | 10.6 | 83.2 | 83.2 |
| 100 | 13.8 | 13.8 | 4.6 | 4.6 | 87.8 | 87.8 |
| 200 | 23.6 | 23.6 | 7.9 | 7.9 | 95.7 | 95.7 |
| Pan | 13.0 | 13.0 | 4.3 | 4.3 | 100.0 | 100.0 |
| Total | 300.5 | 300.5 | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | |
|------------|-----------|--------------|------------|------------|-------------|--------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. |
| 3/8 | 2.7 | 2.7 | 0.9 | 0.9 | 0.9 | 0.9 |
| 4 | 5.0 | 5.0 | 1.6 | 1.6 | 2.5 | 2.5 |
| 10 | 22.6 | 22.6 | 7.3 | 7.3 | 9.8 | 9.8 |
| 20 | 33.9 | 33.9 | 11.0 | 11.0 | 20.8 | 20.8 |
| 40 | 80.3 | 80.3 | 26.0 | 26.0 | 46.8 | 46.8 |
| 60 | 79.4 | 79.4 | 25.7 | 25.7 | 72.6 | 72.6 |
| 80 | 34.0 | 34.0 | 11.0 | 11.0 | 83.6 | 83.6 |
| 100 | 13.8 | 13.8 | 4.5 | 4.5 | 88.1 | 88.1 |
| 200 | 25.9 | 25.9 | 8.4 | 8.4 | 96.5 | 96.5 |
| Pan | 10.9 | 10.9 | 3.5 | 3.5 | 100.0 | 100.0 |
| Total | 308.5 | 308.5 | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | |
|------------|-----------|--------------|------------|------------|-------------|--------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. |
| 3/8 | 8.8 | 8.8 | 2.6 | 2.6 | 2.6 | 2.6 |
| 4 | 12.6 | 12.6 | 3.7 | 3.7 | 6.3 | 6.3 |
| 10 | 22.7 | 22.7 | 6.7 | 6.7 | 13.1 | 13.1 |
| 20 | 39.3 | 39.3 | 11.7 | 11.7 | 24.7 | 24.7 |
| 40 | 107.0 | 107.0 | 31.7 | 31.7 | 56.5 | 56.5 |
| 60 | 83.0 | 83.0 | 24.6 | 24.6 | 81.1 | 81.1 |
| 80 | 27.0 | 27.0 | 8.0 | 8.0 | 89.1 | 89.1 |
| 100 | 9.5 | 9.5 | 2.8 | 2.8 | 91.9 | 91.9 |
| 200 | 16.7 | 16.7 | 5.0 | 5.0 | 96.9 | 96.9 |
| Pan | 10.6 | 10.6 | 3.1 | 3.1 | 100.0 | 100.0 |
| Total | 337.2 | 337.2 | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | |
|------------|-----------|--------------|------------|------------|-------------|--------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. |
| 3/8 | 14.3 | 14.3 | 4.9 | 4.9 | 4.9 | 4.9 |
| 4 | 2.5 | 2.5 | 0.9 | 0.9 | 5.8 | 5.8 |
| 10 | 7.0 | 7.0 | 2.4 | 2.4 | 8.2 | 8.2 |
| 20 | 27.6 | 27.6 | 9.5 | 9.5 | 17.6 | 17.6 |
| 40 | 104.7 | 104.7 | 35.9 | 35.9 | 53.5 | 53.5 |
| 60 | 84.9 | 84.9 | 29.1 | 29.1 | 82.6 | 82.6 |
| 80 | 23.0 | 23.0 | 7.9 | 7.9 | 90.5 | 90.5 |
| 100 | 7.7 | 7.7 | 2.6 | 2.6 | 93.2 | 93.2 |
| 200 | 10.7 | 10.7 | 3.7 | 3.7 | 96.8 | 96.8 |
| Pan | 9.2 | 9.2 | 3.2 | 3.2 | 100.0 | 100.0 |
| Total | 291.6 | 291.6 | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | |
|------------|-----------|--------------|------------|------------|-------------|--------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. |
| 3/8 | 50.5 | 50.5 | 13.6 | 13.6 | 13.6 | 13.6 |
| 4 | 15.0 | 15.0 | 4.1 | 4.1 | 17.7 | 17.7 |
| 10 | 19.9 | 19.9 | 5.4 | 5.4 | 23.1 | 23.1 |
| 20 | 41.8 | 41.8 | 11.3 | 11.3 | 34.4 | 34.4 |
| 40 | 121.5 | 121.5 | 32.8 | 32.8 | 67.2 | 67.2 |
| 60 | 85.8 | 85.8 | 23.2 | 23.2 | 90.3 | 90.3 |
| 80 | 17.3 | 17.3 | 4.7 | 4.7 | 95.0 | 95.0 |
| 100 | 4.7 | 4.7 | 1.3 | 1.3 | 96.3 | 96.3 |
| 200 | 6.7 | 6.7 | 1.8 | 1.8 | 98.1 | 98.1 |
| Pan | 7.1 | 7.1 | 1.9 | 1.9 | 100.0 | 100.0 |
| Total | 370.3 | 370.3 | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | |
|------------|-----------|--------------|------------|------------|-------------|--------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. |
| 3/8 | 25.6 | 25.6 | 7.1 | 7.1 | 7.1 | 7.1 |
| 4 | 33.6 | 33.6 | 9.3 | 9.3 | 16.4 | 16.4 |
| 10 | 47.4 | 47.4 | 13.1 | 13.1 | 29.5 | 29.5 |
| 20 | 53.3 | 53.3 | 14.7 | 14.7 | 44.2 | 44.2 |
| 40 | 113.5 | 113.5 | 31.4 | 31.4 | 75.6 | 75.6 |
| 60 | 59.4 | 59.4 | 16.4 | 16.4 | 92.0 | 92.0 |
| 80 | 9.8 | 9.8 | 2.7 | 2.7 | 94.7 | 94.7 |
| 100 | 3.2 | 3.2 | 0.9 | 0.9 | 95.6 | 95.6 |
| 200 | 7.0 | 7.0 | 1.9 | 1.9 | 97.6 | 97.6 |
| Pan | 8.8 | 8.8 | 2.4 | 2.4 | 100.0 | 100.0 |
| Total | 361.6 | 361.6 | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | |
|------------|-----------|--------------|------------|------------|-------------|--------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. |
| 3/8 | 10.2 | 10.2 | 3.2 | 3.2 | 3.2 | 3.2 |
| 4 | 10.8 | 10.8 | 3.3 | 3.3 | 6.5 | 6.5 |
| 10 | 10.8 | 10.8 | 3.3 | 3.3 | 9.8 | 9.8 |
| 20 | 22.6 | 22.6 | 7.0 | 7.0 | 16.8 | 16.8 |
| 40 | 97.9 | 97.9 | 30.3 | 30.3 | 47.1 | 47.1 |
| 60 | 84.0 | 84.0 | 26.0 | 26.0 | 73.0 | 73.0 |
| 80 | 39.9 | 39.9 | 12.3 | 12.3 | 85.4 | 85.4 |
| 100 | 18.0 | 18.0 | 5.6 | 5.6 | 90.9 | 90.9 |
| 200 | 21.6 | 21.6 | 6.7 | 6.7 | 97.6 | 97.6 |
| Pan | 7.8 | 7.8 | 2.4 | 2.4 | 100.0 | 100.0 |
| Total | 323.6 | 323.6 | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | |
|------------|-----------|--------------|------------|------------|-------------|--------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. |
| 3/8 | 22.3 | 22.3 | 10.0 | 10.0 | 10.0 | 10.0 |
| 4 | 15.7 | 15.7 | 7.1 | 7.1 | 17.1 | 17.1 |
| 10 | 16.1 | 16.1 | 7.2 | 7.2 | 24.3 | 24.3 |
| 20 | 32.2 | 32.2 | 14.5 | 14.5 | 38.8 | 38.8 |
| 40 | 72.0 | 72.0 | 32.3 | 32.3 | 71.1 | 71.1 |
| 60 | 41.7 | 41.7 | 18.7 | 18.7 | 89.8 | 89.8 |
| 80 | 8.3 | 8.3 | 3.7 | 3.7 | 93.6 | 93.6 |
| 100 | 2.8 | 2.8 | 1.3 | 1.3 | 94.8 | 94.8 |
| 200 | 5.2 | 5.2 | 2.3 | 2.3 | 97.2 | 97.2 |
| Pan | 6.3 | 6.3 | 2.8 | 2.8 | 100.0 | 100.0 |
| Total | 222.6 | 222.6 | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 10 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 62.4 | 19.7 | 19.7 | 19.7 | 19.7 | 0.0 | 316.8 |
| 4 | 6.6 | 2.1 | 2.1 | 2.1 | 2.1 | 0.0 | 78.2 |
| 10 | 3.9 | 1.2 | 23.0 | 77.0 | 23.0 | 0.0 | 77.0 |
| 20 | 2.8 | 0.9 | 23.9 | 76.1 | 23.9 | 0.0 | 76.1 |
| 40 | 2.0 | 6.3 | 30.2 | 69.8 | 30.2 | 0.0 | 69.8 |
| 60 | 88.5 | 27.9 | 58.1 | 41.9 | 58.1 | 0.0 | 41.9 |
| 80 | 57.9 | 18.3 | 76.4 | 23.6 | 76.4 | 0.0 | 23.6 |
| 100 | 23.7 | 7.5 | 83.9 | 16.1 | 83.9 | 0.0 | 16.1 |
| 200 | 35.2 | 11.1 | 95.0 | 5.0 | 95.0 | 0.0 | 5.0 |
| Pan | 15.8 | 5.0 | 100.0 | 0.0 | 100.0 | 0.0 | 0.0 |
| Total | | | | | | | 316.8 |

| Sieve Size | Boring | | 12-AY | | Sample | | 13 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 226.2 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 1.6 | 0.7 | 0.7 | 99.3 | 0.7 | 0.0 | 99.3 |
| 20 | 23.6 | 10.4 | 11.1 | 88.9 | 11.1 | 0.0 | 88.9 |
| 40 | 82.1 | 36.3 | 47.4 | 52.6 | 47.4 | 0.0 | 52.6 |
| 60 | 69.3 | 30.6 | 78.1 | 21.9 | 78.1 | 0.0 | 21.9 |
| 80 | 21.6 | 9.5 | 87.6 | 12.4 | 87.6 | 0.0 | 12.4 |
| 100 | 7.6 | 3.4 | 91.0 | 9.0 | 91.0 | 0.0 | 9.0 |
| 200 | 11.1 | 4.9 | 95.9 | 4.1 | 95.9 | 0.0 | 4.1 |
| Pan | 9.3 | 4.1 | 100.0 | 0.0 | 100.0 | 0.0 | 0.0 |
| Total | | | | | | | 226.2 |

| Sieve Size | Boring | | 12-AY | | Sample | | 16 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 314.4 |
| 4 | 1.0 | 0.3 | 0.3 | 99.7 | 0.3 | 0.0 | 99.7 |
| 10 | 1.5 | 0.5 | 0.8 | 99.2 | 0.8 | 0.0 | 99.2 |
| 20 | 12.4 | 3.9 | 4.7 | 95.3 | 4.7 | 0.0 | 95.3 |
| 40 | 92.4 | 29.4 | 34.1 | 65.9 | 34.1 | 0.0 | 65.9 |
| 60 | 130.7 | 41.6 | 75.7 | 24.3 | 75.7 | 0.0 | 24.3 |
| 80 | 42.5 | 13.5 | 89.2 | 10.8 | 89.2 | 0.0 | 10.8 |
| 100 | 12.7 | 4.0 | 93.3 | 6.7 | 93.3 | 0.0 | 6.7 |
| 200 | 14.8 | 4.7 | 98.0 | 2.0 | 98.0 | 0.0 | 2.0 |
| Pan | 6.4 | 2.0 | 100.0 | 0.0 | 100.0 | 0.0 | 0.0 |
| Total | | | | | | | 314.4 |

| Sieve Size | Boring | | 12-AY | | Sample | | 11 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 353.5 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.4 | 0.1 | 0.1 | 99.9 | 0.1 | 0.0 | 99.9 |
| 20 | 3.9 | 1.1 | 1.2 | 98.8 | 1.2 | 0.0 | 98.8 |
| 40 | 109.8 | 31.1 | 32.3 | 67.7 | 32.3 | 0.0 | 67.7 |
| 60 | 153.7 | 43.5 | 75.8 | 24.2 | 75.8 | 0.0 | 24.2 |
| 80 | 46.7 | 13.2 | 89.0 | 11.0 | 89.0 | 0.0 | 11.0 |
| 100 | 15.4 | 4.4 | 93.3 | 6.7 | 93.3 | 0.0 | 6.7 |
| 200 | 17.5 | 5.0 | 98.3 | 1.7 | 98.3 | 0.0 | 1.7 |
| Pan | 6.1 | 1.7 | 100.0 | 0.0 | 100.0 | 0.0 | 0.0 |
| Total | | | | | | | 353.5 |

| Sieve Size | Boring | | 12-AY | | Sample | | 14 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 365.7 |
| 4 | 0.9 | 0.2 | 0.2 | 99.8 | 0.2 | 0.0 | 99.8 |
| 10 | 9.7 | 2.7 | 2.9 | 97.1 | 2.9 | 0.0 | 97.1 |
| 20 | 61.3 | 16.8 | 19.7 | 80.3 | 19.7 | 0.0 | 80.3 |
| 40 | 146.3 | 40.0 | 59.7 | 40.3 | 59.7 | 0.0 | 40.3 |
| 60 | 92.0 | 25.2 | 84.8 | 15.2 | 84.8 | 0.0 | 15.2 |
| 80 | 27.6 | 7.5 | 92.4 | 7.6 | 92.4 | 0.0 | 7.6 |
| 100 | 8.5 | 2.3 | 94.7 | 5.3 | 94.7 | 0.0 | 5.3 |
| 200 | 12.9 | 3.5 | 98.2 | 1.8 | 98.2 | 0.0 | 1.8 |
| Pan | 6.5 | 1.8 | 100.0 | 0.0 | 100.0 | 0.0 | 0.0 |
| Total | | | | | | | 365.7 |

| Sieve Size | Boring | | 12-AY | | Sample | | 17 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 243.9 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.3 | 0.1 | 0.1 | 99.9 | 0.1 | 0.0 | 99.9 |
| 20 | 4.0 | 1.6 | 1.8 | 98.2 | 1.8 | 0.0 | 98.2 |
| 40 | 53.4 | 21.9 | 23.7 | 76.3 | 23.7 | 0.0 | 76.3 |
| 60 | 97.8 | 40.1 | 63.8 | 36.2 | 63.8 | 0.0 | 36.2 |
| 80 | 34.4 | 14.1 | 77.9 | 22.1 | 77.9 | 0.0 | 22.1 |
| 100 | 12.2 | 5.0 | 82.9 | 17.1 | 82.9 | 0.0 | 17.1 |
| 200 | 27.2 | 11.2 | 94.0 | 6.0 | 94.0 | 0.0 | 6.0 |
| Pan | 14.6 | 6.0 | 100.0 | 0.0 | 100.0 | 0.0 | 0.0 |
| Total | | | | | | | 243.9 |

| Sieve Size | Boring | | 12-AY | | Sample | | 12 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 260.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.6 | 0.2 | 0.2 | 99.8 | 0.2 | 0.0 | 99.8 |
| 20 | 22.5 | 8.7 | 8.9 | 91.1 | 8.9 | 0.0 | 91.1 |
| 40 | 105.6 | 40.6 | 49.5 | 50.5 | 49.5 | 0.0 | 50.5 |
| 60 | 84.1 | 32.3 | 81.8 | 18.2 | 81.8 | 0.0 | 18.2 |
| 80 | 22.5 | 8.7 | 90.5 | 9.5 | 90.5 | 0.0 | 9.5 |
| 100 | 7.2 | 2.8 | 93.3 | 6.7 | 93.3 | 0.0 | 6.7 |
| 200 | 10.1 | 3.9 | 97.2 | 2.8 | 97.2 | 0.0 | 2.8 |
| Pan | 7.4 | 2.8 | 100.0 | 0.0 | 100.0 | 0.0 | 0.0 |
| Total | | | | | | | 260.0 |

| Sieve Size | Boring | | 12-AY | | Sample | | 15 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 268.8 |
| 4 | 0.2 | 0.1 | 0.1 | 99.9 | 0.1 | 0.0 | 99.9 |
| 10 | 1.9 | 0.7 | 0.8 | 99.2 | 0.8 | 0.0 | 99.2 |
| 20 | 18.2 | 6.8 | 7.6 | 92.4 | 7.6 | 0.0 | 92.4 |
| 40 | 98.8 | 36.8 | 44.3 | 55.7 | 44.3 | 0.0 | 55.7 |
| 60 | 90.8 | 33.8 | 78.1 | 21.9 | 78.1 | 0.0 | 21.9 |
| 80 | 28.1 | 10.5 | 88.5 | 11.5 | 88.5 | 0.0 | 11.5 |
| 100 | 8.4 | 3.1 | 91.7 | 8.3 | 91.7 | 0.0 | 8.3 |
| 200 | 13.7 | 5.1 | 96.8 | 3.2 | 96.8 | 0.0 | 3.2 |
| Pan | 8.7 | 3.2 | 100.0 | 0.0 | 100.0 | 0.0 | 0.0 |
| Total | | | | | | | 268.8 |

| Sieve Size | Boring | | 12-AY | | Sample | | 18 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 299.5 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.4 | 0.1 | 0.1 | 99.9 | 0.1 | 0.0 | 99.9 |
| 20 | 2.6 | 0.9 | 1.0 | 99.0 | 1.0 | 0.0 | 99.0 |
| 40 | 15.8 | 5.3 | 6.3 | 93.7 | 6.3 | 0.0 | 93.7 |
| 60 | 37.2 | 12.4 | 18.7 | 81.3 | 18.7 | 0.0 | 81.3 |
| 80 | 33.5 | 11.2 | 29.9 | 70.1 | 29.9 | 0.0 | 70.1 |
| 100 | 24.8 | 8.3 | 38.2 | 61.8 | 38.2 | 0.0 | 61.8 |
| 200 | 105.1 | 35.1 | 73.3 | 26.7 | 73.3 | 0.0 | 26.7 |
| Pan | 80.1 | 26.7 | 100.0 | 0.0 | 100.0 | 0.0 | 0.0 |
| Total | | | | | | | 299.5 |

| Sieve Size | Boring | | 12-AY | | Sample | | 19 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | 250.3 |
| 3/8 | 1.5 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 99.4 |
| 4 | 2.0 | 0.8 | 0.8 | 1.4 | 1.4 | 1.4 | 98.6 |
| 10 | 1.7 | 0.7 | 0.7 | 2.1 | 2.1 | 2.1 | 97.9 |
| 20 | 8.6 | 3.4 | 3.4 | 5.5 | 5.5 | 5.5 | 94.5 |
| 40 | 43.5 | 17.4 | 22.9 | 22.9 | 22.9 | 22.9 | 77.1 |
| 60 | 89.4 | 35.7 | 58.6 | 58.6 | 58.6 | 58.6 | 41.4 |
| 80 | 61.4 | 24.5 | 83.1 | 83.1 | 83.1 | 83.1 | 16.9 |
| 100 | 19.8 | 7.9 | 91.1 | 91.1 | 91.1 | 91.1 | 8.9 |
| 200 | 17.0 | 6.8 | 97.8 | 97.8 | 97.8 | 97.8 | 2.2 |
| Pan | 5.4 | 2.2 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | 250.3 | | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 22 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | 306.1 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 40 | 0.4 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 99.9 |
| 60 | 20.0 | 6.5 | 6.7 | 6.7 | 6.7 | 6.7 | 93.3 |
| 80 | 60.7 | 19.8 | 26.5 | 26.5 | 26.5 | 26.5 | 73.5 |
| 100 | 51.3 | 16.8 | 43.3 | 43.3 | 43.3 | 43.3 | 56.7 |
| 200 | 139.4 | 45.5 | 88.8 | 88.8 | 88.8 | 88.8 | 11.2 |
| Pan | 34.3 | 11.2 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | 306.1 | | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 25 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | 301.8 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 99.9 |
| 40 | 6.0 | 2.0 | 2.1 | 2.1 | 2.1 | 2.1 | 97.9 |
| 60 | 85.9 | 28.5 | 30.5 | 30.5 | 30.5 | 30.5 | 69.5 |
| 80 | 106.3 | 35.2 | 65.7 | 65.7 | 65.7 | 65.7 | 34.3 |
| 100 | 42.5 | 14.1 | 79.8 | 79.8 | 79.8 | 79.8 | 20.2 |
| 200 | 47.2 | 15.6 | 95.5 | 95.5 | 95.5 | 95.5 | 4.5 |
| Pan | 13.7 | 4.5 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | 301.8 | | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 20 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | 326.8 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 99.9 |
| 20 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 99.5 |
| 40 | 7.1 | 2.2 | 2.7 | 2.7 | 2.7 | 2.7 | 97.3 |
| 60 | 35.1 | 10.7 | 13.4 | 13.4 | 13.4 | 13.4 | 86.6 |
| 80 | 79.9 | 24.4 | 37.9 | 37.9 | 37.9 | 37.9 | 62.1 |
| 100 | 58.7 | 18.0 | 55.8 | 55.8 | 55.8 | 55.8 | 44.2 |
| 200 | 120.3 | 36.8 | 92.7 | 92.7 | 92.7 | 92.7 | 7.3 |
| Pan | 24.0 | 7.3 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | 326.8 | | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 23 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | 312.1 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 40 | 0.4 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 99.8 |
| 60 | 18.0 | 5.8 | 5.9 | 5.9 | 5.9 | 5.9 | 94.1 |
| 80 | 45.3 | 14.5 | 20.4 | 20.4 | 20.4 | 20.4 | 79.6 |
| 100 | 44.5 | 14.3 | 34.7 | 34.7 | 34.7 | 34.7 | 65.3 |
| 200 | 140.6 | 45.0 | 79.8 | 79.8 | 79.8 | 79.8 | 20.2 |
| Pan | 63.2 | 20.2 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | 312.1 | | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 26 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | 308.8 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.4 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 99.9 |
| 40 | 11.5 | 3.7 | 3.9 | 3.9 | 3.9 | 3.9 | 96.1 |
| 60 | 71.3 | 23.1 | 26.9 | 26.9 | 26.9 | 26.9 | 73.1 |
| 80 | 75.0 | 24.3 | 51.2 | 51.2 | 51.2 | 51.2 | 48.8 |
| 100 | 43.1 | 14.0 | 65.2 | 65.2 | 65.2 | 65.2 | 34.8 |
| 200 | 79.0 | 25.6 | 90.8 | 90.8 | 90.8 | 90.8 | 9.2 |
| Pan | 28.5 | 9.2 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | 308.8 | | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 21 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | 308.9 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 99.9 |
| 10 | 0.4 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 99.8 |
| 20 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 99.3 |
| 40 | 8.2 | 2.7 | 3.3 | 3.3 | 3.3 | 3.3 | 96.7 |
| 60 | 31.0 | 10.0 | 13.4 | 13.4 | 13.4 | 13.4 | 86.6 |
| 80 | 72.6 | 23.5 | 36.9 | 36.9 | 36.9 | 36.9 | 63.1 |
| 100 | 51.5 | 16.7 | 53.5 | 53.5 | 53.5 | 53.5 | 46.5 |
| 200 | 118.9 | 38.5 | 92.0 | 92.0 | 92.0 | 92.0 | 8.0 |
| Pan | 24.6 | 8.0 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | 308.9 | | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 24 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | 328.6 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 40 | 0.8 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 99.8 |
| 60 | 27.0 | 8.2 | 8.5 | 8.5 | 8.5 | 8.5 | 91.5 |
| 80 | 103.4 | 31.5 | 39.9 | 39.9 | 39.9 | 39.9 | 60.1 |
| 100 | 64.8 | 19.7 | 59.6 | 59.6 | 59.6 | 59.6 | 40.4 |
| 200 | 109.5 | 33.3 | 93.0 | 93.0 | 93.0 | 93.0 | 7.0 |
| Pan | 23.1 | 7.0 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | 328.6 | | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 27 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | 300.0 |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.7 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 99.7 |
| 40 | 9.5 | 3.2 | 3.4 | 3.4 | 3.4 | 3.4 | 96.6 |
| 60 | 62.3 | 20.8 | 24.2 | 24.2 | 24.2 | 24.2 | 75.8 |
| 80 | 67.3 | 22.4 | 46.6 | 46.6 | 46.6 | 46.6 | 53.4 |
| 100 | 30.7 | 10.2 | 56.9 | 56.9 | 56.9 | 56.9 | 43.1 |
| 200 | 80.9 | 27.0 | 83.8 | 83.8 | 83.8 | 83.8 | 16.2 |
| Pan | 48.5 | 16.2 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | 300.0 | | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 28 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 302.7 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 40 | 0.1 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 99.9 |
| 60 | 6.7 | 2.2 | 2.3 | 97.7 | 2.3 | 2.3 | 97.7 |
| 80 | 40.3 | 13.3 | 15.6 | 84.4 | 15.6 | 15.6 | 84.4 |
| 100 | 34.9 | 11.5 | 27.1 | 72.9 | 27.1 | 27.1 | 72.9 |
| 200 | 128.7 | 42.5 | 69.6 | 30.4 | 69.6 | 69.6 | 30.4 |
| Pan | 91.9 | 30.4 | 100.0 | 0.0 | 100.0 | 100.0 | 0.0 |
| Total | 302.7 | | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 31 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 40 | 5.3 | 1.7 | 1.7 | 98.3 | 1.7 | 1.7 | 98.3 |
| 60 | 70.4 | 22.9 | 24.6 | 75.4 | 24.6 | 24.6 | 75.4 |
| 80 | 95.3 | 31.0 | 55.6 | 44.4 | 55.6 | 55.6 | 44.4 |
| 100 | 42.5 | 13.8 | 69.4 | 30.6 | 69.4 | 69.4 | 30.6 |
| 200 | 77.7 | 25.3 | 94.6 | 5.4 | 94.6 | 94.6 | 5.4 |
| Pan | 16.5 | 5.4 | 100.0 | 0.0 | 100.0 | 100.0 | 0.0 |
| Total | 307.7 | | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 34 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.4 | 0.1 | 0.1 | 99.9 | 0.1 | 0.1 | 99.9 |
| 20 | 14.4 | 4.4 | 4.6 | 95.4 | 4.6 | 4.6 | 95.4 |
| 40 | 144.8 | 44.7 | 49.2 | 50.8 | 49.2 | 49.2 | 50.8 |
| 60 | 121.1 | 37.4 | 86.6 | 13.4 | 86.6 | 86.6 | 13.4 |
| 80 | 22.5 | 6.9 | 93.6 | 6.4 | 93.6 | 93.6 | 6.4 |
| 100 | 5.7 | 1.8 | 95.3 | 4.7 | 95.3 | 95.3 | 4.7 |
| 200 | 7.2 | 2.2 | 97.5 | 2.5 | 97.5 | 97.5 | 2.5 |
| Pan | 8.0 | 2.5 | 100.0 | 0.0 | 100.0 | 100.0 | 0.0 |
| Total | 324.1 | | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 29 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 329.9 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.2 | 0.1 | 0.1 | 99.9 | 0.1 | 0.1 | 99.9 |
| 40 | 2.6 | 0.8 | 0.8 | 99.2 | 0.8 | 0.8 | 99.2 |
| 60 | 19.3 | 5.9 | 6.7 | 93.3 | 6.7 | 6.7 | 93.3 |
| 80 | 34.8 | 10.5 | 17.2 | 82.8 | 17.2 | 17.2 | 82.8 |
| 100 | 33.4 | 10.1 | 27.4 | 72.6 | 27.4 | 27.4 | 72.6 |
| 200 | 165.1 | 50.0 | 77.4 | 22.6 | 77.4 | 77.4 | 22.6 |
| Pan | 74.5 | 22.6 | 100.0 | 0.0 | 100.0 | 100.0 | 0.0 |
| Total | 329.9 | | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 32 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.1 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 100.0 |
| 40 | 16.6 | 5.0 | 5.0 | 95.0 | 5.0 | 5.0 | 95.0 |
| 60 | 118.5 | 35.5 | 40.5 | 59.5 | 40.5 | 40.5 | 59.5 |
| 80 | 81.8 | 24.5 | 64.9 | 35.1 | 64.9 | 64.9 | 35.1 |
| 100 | 29.6 | 8.9 | 73.8 | 26.2 | 73.8 | 73.8 | 26.2 |
| 200 | 61.9 | 18.5 | 92.3 | 7.7 | 92.3 | 92.3 | 7.7 |
| Pan | 25.7 | 7.7 | 100.0 | 0.0 | 100.0 | 100.0 | 0.0 |
| Total | 334.2 | | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 35 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 2.7 | 0.8 | 0.8 | 99.2 | 0.8 | 0.8 | 99.2 |
| 10 | 5.5 | 1.6 | 2.4 | 97.6 | 2.4 | 2.4 | 97.6 |
| 20 | 17.3 | 5.0 | 7.4 | 92.6 | 7.4 | 7.4 | 92.6 |
| 40 | 137.1 | 39.5 | 46.9 | 53.1 | 46.9 | 46.9 | 53.1 |
| 60 | 122.2 | 35.2 | 82.1 | 17.9 | 82.1 | 82.1 | 17.9 |
| 80 | 28.3 | 8.2 | 90.3 | 9.7 | 90.3 | 90.3 | 9.7 |
| 100 | 8.8 | 2.5 | 92.8 | 7.2 | 92.8 | 92.8 | 7.2 |
| 200 | 14.4 | 4.2 | 96.9 | 3.1 | 96.9 | 96.9 | 3.1 |
| Pan | 10.6 | 3.1 | 100.0 | 0.0 | 100.0 | 100.0 | 0.0 |
| Total | 346.9 | | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 30 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.2 | 0.1 | 0.1 | 99.9 | 0.1 | 0.1 | 99.9 |
| 40 | 5.0 | 1.5 | 1.5 | 98.4 | 1.5 | 1.5 | 98.4 |
| 60 | 45.0 | 13.7 | 15.3 | 84.7 | 15.3 | 15.3 | 84.7 |
| 80 | 76.4 | 23.2 | 38.5 | 61.5 | 38.5 | 38.5 | 61.5 |
| 100 | 50.8 | 15.4 | 53.9 | 46.1 | 53.9 | 53.9 | 46.1 |
| 200 | 113.2 | 34.4 | 88.4 | 11.6 | 88.4 | 88.4 | 11.6 |
| Pan | 38.3 | 11.6 | 100.0 | 0.0 | 100.0 | 100.0 | 0.0 |
| Total | 328.9 | | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 33 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.3 | 0.1 | 0.1 | 99.9 | 0.1 | 0.1 | 99.9 |
| 20 | 13.2 | 5.9 | 6.0 | 94.0 | 6.0 | 6.0 | 94.0 |
| 40 | 93.2 | 41.6 | 47.6 | 52.4 | 47.6 | 47.6 | 52.4 |
| 60 | 85.7 | 38.2 | 85.8 | 14.2 | 85.8 | 85.8 | 14.2 |
| 80 | 17.7 | 7.9 | 93.7 | 6.3 | 93.7 | 93.7 | 6.3 |
| 100 | 4.7 | 2.1 | 95.8 | 4.2 | 95.8 | 95.8 | 4.2 |
| 200 | 6.0 | 2.7 | 98.4 | 1.6 | 98.4 | 98.4 | 1.6 |
| Pan | 3.5 | 1.6 | 100.0 | 0.0 | 100.0 | 100.0 | 0.0 |
| Total | 224.3 | | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 36 |
|------------|-----------|--------------|------------|------------|-------------|--------|------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 4.6 | 1.5 | 1.5 | 98.5 | 1.5 | 1.5 | 98.5 |
| 4 | 11.8 | 3.7 | 5.2 | 94.8 | 5.2 | 5.2 | 94.8 |
| 10 | 15.8 | 5.0 | 10.2 | 89.8 | 10.2 | 10.2 | 89.8 |
| 20 | 23.6 | 7.5 | 17.6 | 82.4 | 17.6 | 17.6 | 82.4 |
| 40 | 108.6 | 34.3 | 52.0 | 48.0 | 52.0 | 52.0 | 48.0 |
| 60 | 116.2 | 36.7 | 88.7 | 11.3 | 88.7 | 88.7 | 11.3 |
| 80 | 19.1 | 6.0 | 94.7 | 5.3 | 94.7 | 94.7 | 5.3 |
| 100 | 3.5 | 1.1 | 95.8 | 4.2 | 95.8 | 95.8 | 4.2 |
| 200 | 5.5 | 1.7 | 97.6 | 2.4 | 97.6 | 97.6 | 2.4 |
| Pan | 7.7 | 2.4 | 100.0 | 0.0 | 100.0 | 100.0 | 0.0 |
| Total | 316.4 | | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 215 |
|------------|-----------|--------------|----------|------------|-------------|------------|---------|
| | Depth (m) | Soil Wt. (g) | Retained | % Retained | Dry Wt. (g) | Accum. | 220.4 |
| | | | | | | % Retained | % Finer |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 2.7 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 98.8 |
| 20 | 10.1 | 4.6 | 5.8 | 5.8 | 5.8 | 5.8 | 94.2 |
| 40 | 71.1 | 32.3 | 38.1 | 38.1 | 61.9 | 61.9 | 61.9 |
| 60 | 75.4 | 34.2 | 72.3 | 72.3 | 27.7 | 27.7 | 27.7 |
| 80 | 24.0 | 10.9 | 83.2 | 83.2 | 16.8 | 16.8 | 16.8 |
| 100 | 8.8 | 4.0 | 87.2 | 87.2 | 12.8 | 12.8 | 12.8 |
| 200 | 18.0 | 8.2 | 95.3 | 95.3 | 4.7 | 4.7 | 4.7 |
| Pan | 10.3 | 4.7 | 100.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| Total | | 220.4 | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 218 |
|------------|-----------|--------------|----------|------------|-------------|------------|---------|
| | Depth (m) | Soil Wt. (g) | Retained | % Retained | Dry Wt. (g) | Accum. | 346.3 |
| | | | | | | % Retained | % Finer |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.5 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 99.9 |
| 20 | 9.6 | 2.8 | 2.9 | 2.9 | 97.1 | 97.1 | 97.1 |
| 40 | 94.2 | 27.2 | 30.1 | 30.1 | 69.9 | 69.9 | 69.9 |
| 60 | 164.2 | 47.4 | 77.5 | 77.5 | 22.5 | 22.5 | 22.5 |
| 80 | 44.4 | 12.8 | 90.4 | 90.4 | 9.6 | 9.6 | 9.6 |
| 100 | 10.3 | 3.0 | 93.3 | 93.3 | 6.7 | 6.7 | 6.7 |
| 200 | 13.1 | 3.8 | 97.1 | 97.1 | 2.9 | 2.9 | 2.9 |
| Pan | 10.0 | 2.9 | 100.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| Total | | 346.3 | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 68 |
|------------|-----------|--------------|----------|------------|-------------|------------|---------|
| | Depth (m) | Soil Wt. (g) | Retained | % Retained | Dry Wt. (g) | Accum. | 178.3 |
| | | | | | | % Retained | % Finer |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 3.2 | 1.8 | 1.8 | 1.8 | 98.2 | 98.2 | 98.2 |
| 40 | 80.0 | 44.9 | 46.7 | 46.7 | 53.3 | 53.3 | 53.3 |
| 60 | 75.2 | 42.2 | 88.8 | 88.8 | 11.2 | 11.2 | 11.2 |
| 80 | 12.8 | 7.2 | 96.0 | 96.0 | 4.0 | 4.0 | 4.0 |
| 100 | 2.6 | 1.5 | 97.5 | 97.5 | 2.5 | 2.5 | 2.5 |
| 200 | 3.2 | 1.8 | 99.3 | 99.3 | 0.7 | 0.7 | 0.7 |
| Pan | 1.3 | 0.7 | 100.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| Total | | 178.3 | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 214 |
|------------|-----------|--------------|----------|------------|-------------|------------|---------|
| | Depth (m) | Soil Wt. (g) | Retained | % Retained | Dry Wt. (g) | Accum. | 370.8 |
| | | | | | | % Retained | % Finer |
| 3/8 | 4.7 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 98.7 |
| 4 | 0.7 | 0.2 | 1.5 | 1.5 | 98.5 | 98.5 | 98.5 |
| 10 | 1.1 | 0.3 | 1.8 | 1.8 | 98.2 | 98.2 | 98.2 |
| 20 | 9.6 | 2.6 | 4.3 | 4.3 | 95.7 | 95.7 | 95.7 |
| 40 | 110.0 | 29.7 | 34.0 | 34.0 | 66.0 | 66.0 | 66.0 |
| 60 | 180.4 | 48.7 | 82.7 | 82.7 | 17.3 | 17.3 | 17.3 |
| 80 | 37.3 | 10.1 | 92.7 | 92.7 | 7.3 | 7.3 | 7.3 |
| 100 | 7.0 | 1.9 | 94.6 | 94.6 | 5.4 | 5.4 | 5.4 |
| 200 | 8.6 | 2.3 | 96.9 | 96.9 | 3.1 | 3.1 | 3.1 |
| Pan | 11.4 | 3.1 | 100.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| Total | | 370.8 | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 217 |
|------------|-----------|--------------|----------|------------|-------------|------------|---------|
| | Depth (m) | Soil Wt. (g) | Retained | % Retained | Dry Wt. (g) | Accum. | 315.3 |
| | | | | | | % Retained | % Finer |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.2 | 0.1 | 0.1 | 0.1 | 99.9 | 99.9 | 99.9 |
| 10 | 0.0 | 0.0 | 0.1 | 0.1 | 99.9 | 99.9 | 99.9 |
| 20 | 3.1 | 1.0 | 1.0 | 1.0 | 99.0 | 99.0 | 99.0 |
| 40 | 94.0 | 29.8 | 30.9 | 30.9 | 69.1 | 69.1 | 69.1 |
| 60 | 148.7 | 47.2 | 78.0 | 78.0 | 22.0 | 22.0 | 22.0 |
| 80 | 35.7 | 11.3 | 89.3 | 89.3 | 10.7 | 10.7 | 10.7 |
| 100 | 7.6 | 2.4 | 91.8 | 91.8 | 8.2 | 8.2 | 8.2 |
| 200 | 10.9 | 3.5 | 95.2 | 95.2 | 4.8 | 4.8 | 4.8 |
| Pan | 15.1 | 4.8 | 100.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| Total | | 315.3 | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 67 |
|------------|-----------|--------------|----------|------------|-------------|------------|---------|
| | Depth (m) | Soil Wt. (g) | Retained | % Retained | Dry Wt. (g) | Accum. | 146.5 |
| | | | | | | % Retained | % Finer |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 4.3 | 2.9 | 2.9 | 2.9 | 97.1 | 97.1 | 97.1 |
| 40 | 65.9 | 45.0 | 47.9 | 47.9 | 52.1 | 52.1 | 52.1 |
| 60 | 61.9 | 42.3 | 90.2 | 90.2 | 9.8 | 9.8 | 9.8 |
| 80 | 10.0 | 6.8 | 97.0 | 97.0 | 3.0 | 3.0 | 3.0 |
| 100 | 2.0 | 1.4 | 98.4 | 98.4 | 1.6 | 1.6 | 1.6 |
| 200 | 1.7 | 1.2 | 99.5 | 99.5 | 0.5 | 0.5 | 0.5 |
| Pan | 0.7 | 0.5 | 100.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| Total | | 146.5 | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 213 |
|------------|-----------|--------------|----------|------------|-------------|------------|---------|
| | Depth (m) | Soil Wt. (g) | Retained | % Retained | Dry Wt. (g) | Accum. | 410.6 |
| | | | | | | % Retained | % Finer |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.3 | 0.1 | 0.1 | 0.1 | 99.9 | 99.9 | 99.9 |
| 20 | 11.4 | 2.8 | 2.8 | 2.8 | 97.2 | 97.2 | 97.2 |
| 40 | 140.6 | 34.2 | 37.1 | 37.1 | 62.9 | 62.9 | 62.9 |
| 60 | 198.7 | 48.4 | 85.5 | 85.5 | 14.5 | 14.5 | 14.5 |
| 80 | 41.2 | 10.0 | 95.5 | 95.5 | 4.5 | 4.5 | 4.5 |
| 100 | 7.5 | 1.8 | 97.3 | 97.3 | 2.7 | 2.7 | 2.7 |
| 200 | 6.3 | 1.5 | 98.9 | 98.9 | 1.1 | 1.1 | 1.1 |
| Pan | 4.6 | 1.1 | 100.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| Total | | 410.6 | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 216 |
|------------|-----------|--------------|----------|------------|-------------|------------|---------|
| | Depth (m) | Soil Wt. (g) | Retained | % Retained | Dry Wt. (g) | Accum. | 369.2 |
| | | | | | | % Retained | % Finer |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.5 | 0.5 | 0.5 | 0.5 | 99.5 | 99.5 | 99.5 |
| 40 | 123.3 | 33.4 | 33.9 | 33.9 | 66.1 | 66.1 | 66.1 |
| 60 | 184.9 | 50.1 | 84.0 | 84.0 | 16.0 | 16.0 | 16.0 |
| 80 | 37.0 | 10.0 | 94.0 | 94.0 | 6.0 | 6.0 | 6.0 |
| 100 | 8.0 | 2.2 | 96.2 | 96.2 | 3.8 | 3.8 | 3.8 |
| 200 | 8.1 | 2.2 | 98.4 | 98.4 | 1.6 | 1.6 | 1.6 |
| Pan | 5.9 | 1.6 | 100.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| Total | | 369.2 | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 66 |
|------------|-----------|--------------|----------|------------|-------------|------------|---------|
| | Depth (m) | Soil Wt. (g) | Retained | % Retained | Dry Wt. (g) | Accum. | 159.7 |
| | | | | | | % Retained | % Finer |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 1.7 | 1.1 | 1.1 | 1.1 | 98.9 | 98.9 | 98.9 |
| 40 | 65.7 | 41.1 | 42.2 | 42.2 | 57.8 | 57.8 | 57.8 |
| 60 | 73.5 | 46.0 | 88.2 | 88.2 | 11.8 | 11.8 | 11.8 |
| 80 | 11.9 | 7.5 | 95.7 | 95.7 | 4.3 | 4.3 | 4.3 |
| 100 | 2.2 | 1.4 | 97.1 | 97.1 | 2.9 | 2.9 | 2.9 |
| 200 | 2.7 | 1.7 | 98.7 | 98.7 | 1.3 | 1.3 | 1.3 |
| Pan | 2.0 | 1.3 | 100.0 | 100.0 | 0.0 | 0.0 | 0.0 |
| Total | | 159.7 | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 65 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 150.9 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 3.6 | 3.6 | 2.4 | 2.4 | 2.4 | 2.4 | 97.6 |
| 40 | 62.8 | 41.6 | 44.0 | 44.0 | 44.0 | 44.0 | 56.0 |
| 60 | 62.1 | 41.2 | 85.2 | 85.2 | 85.2 | 85.2 | 14.8 |
| 80 | 11.2 | 7.4 | 92.6 | 92.6 | 92.6 | 92.6 | 7.4 |
| 100 | 2.4 | 1.6 | 94.2 | 94.2 | 94.2 | 94.2 | 5.8 |
| 200 | 4.6 | 3.0 | 97.2 | 97.2 | 97.2 | 97.2 | 2.8 |
| Pan | 4.2 | 2.8 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | | 150.9 | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 70 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 128.6 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.8 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 99.4 |
| 40 | 41.7 | 32.4 | 33.0 | 33.0 | 33.0 | 33.0 | 67.0 |
| 60 | 64.8 | 50.4 | 83.4 | 83.4 | 83.4 | 83.4 | 16.6 |
| 80 | 14.5 | 11.3 | 94.7 | 94.7 | 94.7 | 94.7 | 5.3 |
| 100 | 3.0 | 2.3 | 97.0 | 97.0 | 97.0 | 97.0 | 3.0 |
| 200 | 2.6 | 2.0 | 99.1 | 99.1 | 99.1 | 99.1 | 0.9 |
| Pan | 1.2 | 0.9 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | | 128.6 | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 73 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 76.3 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.4 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 99.5 |
| 40 | 20.7 | 27.1 | 27.7 | 27.7 | 27.7 | 27.7 | 72.3 |
| 60 | 40.3 | 52.8 | 80.5 | 80.5 | 80.5 | 80.5 | 19.5 |
| 80 | 10.3 | 13.5 | 94.0 | 94.0 | 94.0 | 94.0 | 6.0 |
| 100 | 1.9 | 2.5 | 96.5 | 96.5 | 96.5 | 96.5 | 3.5 |
| 200 | 2.0 | 2.6 | 99.1 | 99.1 | 99.1 | 99.1 | 0.9 |
| Pan | 0.7 | 0.9 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | | 76.3 | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 64 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 73.2 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 2.4 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 96.7 |
| 40 | 28.8 | 39.3 | 42.6 | 42.6 | 42.6 | 42.6 | 57.4 |
| 60 | 30.7 | 41.9 | 84.6 | 84.6 | 84.6 | 84.6 | 15.4 |
| 80 | 6.0 | 8.2 | 92.8 | 92.8 | 92.8 | 92.8 | 7.2 |
| 100 | 1.5 | 2.0 | 94.8 | 94.8 | 94.8 | 94.8 | 5.2 |
| 200 | 1.9 | 2.6 | 97.4 | 97.4 | 97.4 | 97.4 | 2.6 |
| Pan | 1.9 | 2.6 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | | 73.2 | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 69 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 139.5 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.5 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 99.6 |
| 40 | 41.0 | 29.4 | 29.7 | 29.7 | 29.7 | 29.7 | 70.3 |
| 60 | 72.2 | 51.8 | 81.5 | 81.5 | 81.5 | 81.5 | 18.5 |
| 80 | 16.4 | 11.8 | 93.3 | 93.3 | 93.3 | 93.3 | 6.7 |
| 100 | 3.7 | 2.7 | 95.9 | 95.9 | 95.9 | 95.9 | 4.1 |
| 200 | 3.3 | 2.4 | 98.3 | 98.3 | 98.3 | 98.3 | 1.7 |
| Pan | 2.4 | 1.7 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | | 139.5 | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 72 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 89.4 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 0.6 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 99.3 |
| 40 | 23.8 | 26.6 | 27.3 | 27.3 | 27.3 | 27.3 | 72.7 |
| 60 | 46.0 | 51.5 | 78.7 | 78.7 | 78.7 | 78.7 | 21.3 |
| 80 | 12.4 | 13.9 | 92.6 | 92.6 | 92.6 | 92.6 | 7.4 |
| 100 | 2.4 | 2.7 | 95.3 | 95.3 | 95.3 | 95.3 | 4.7 |
| 200 | 2.9 | 3.2 | 98.5 | 98.5 | 98.5 | 98.5 | 1.5 |
| Pan | 1.3 | 1.5 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | | 89.4 | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 71 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 194.3 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 7.5 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 96.1 |
| 40 | 78.7 | 40.5 | 44.4 | 44.4 | 44.4 | 44.4 | 55.6 |
| 60 | 83.0 | 42.7 | 87.1 | 87.1 | 87.1 | 87.1 | 12.9 |
| 80 | 16.7 | 8.6 | 95.7 | 95.7 | 95.7 | 95.7 | 4.3 |
| 100 | 3.7 | 1.9 | 97.6 | 97.6 | 97.6 | 97.6 | 2.4 |
| 200 | 3.1 | 1.6 | 99.2 | 99.2 | 99.2 | 99.2 | 0.8 |
| Pan | 1.6 | 0.8 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | | 194.3 | | | | | |

| Sieve Size | Boring | | 12-AY | | Sample | | 74 |
|------------|-----------|--------------|------------|------------|-------------|--------|-------|
| | Depth (m) | Soil Wt. (g) | % Retained | % Retained | Dry Wt. (g) | Accum. | |
| 3/8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 160.1 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 20 | 1.8 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 98.9 |
| 40 | 49.6 | 31.0 | 32.1 | 32.1 | 32.1 | 32.1 | 67.9 |
| 60 | 81.6 | 51.0 | 83.1 | 83.1 | 83.1 | 83.1 | 16.9 |
| 80 | 18.1 | 11.3 | 94.4 | 94.4 | 94.4 | 94.4 | 5.6 |
| 100 | 3.8 | 2.4 | 96.8 | 96.8 | 96.8 | 96.8 | 3.2 |
| 200 | 3.6 | 2.2 | 99.0 | 99.0 | 99.0 | 99.0 | 1.0 |
| Pan | 1.6 | 1.0 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 |
| Total | | 160.1 | | | | | |

APPENDIX IV SOLID CORE SAMPLING ANALYSES

Plattsburgh Solid Soil Core Data - October 9-13, 1995
Separate Phase Analysis

| Borehole ID | Depth Below Surface (in) | Sample ID | Area | Replicate Area | Mass of Wet Soil (kg) | Mass Moisture Mass Dry Soil (%) | TLV (ppm) | Conc of Sep Phase in Dry Soil (mg/kg) |
|-------------|--------------------------|-----------|---------|----------------|-----------------------|---------------------------------|-----------|---------------------------------------|
| 12-AA | 7.5 | 2 | 0 | | 0.012 | 4.66 | 0 | 0 |
| | 14.5 | 1 | 0 | | 0.012 | 7.45 | 0 | 0 |
| | 70.5 | 4 | 0 | | 0.012 | 6.43 | 0 | 0 |
| | 130.5 | 5 | 0 | | 0.011 | 5.41 | 0 | 0 |
| | 190.5 | 6 | 0 | | 0.013 | 5.43 | 0 | 0 |
| | 250.5 | 7 | 0 | | 0.011 | 10.98 | 0 | 0 |
| | 310.5 | 8 | 0 | | 0.011 | 10.30 | 0 | 0 |
| | 370.5 | 9 | 0 | | 0.014 | 2.68 | 0 | 0 |
| | 422.0 | 13 | 0 | | 0.012 | 5.95 | 0 | 0 |
| | 427.0 | 12 | 0 | | 0.014 | 3.86 | 20 | 0 |
| | 434.0 | 10 | 0 | 0 | 0.012 | 2.67 | 50 | 0 |
| | 434.0 | 11 | 0 | | 0.013 | 2.86 | 50 | 0 |
| | 441.0 | 16 | 0 | | 0.012 | 3.57 | 20 | 0 |
| | 447.0 | 15 | 0 | | 0.012 | 3.60 | 20 | 0 |
| | 453.0 | 14 | 0 | | 0.013 | 3.93 | 30 | 0 |
| | 459.0 | 19 | 0 | | 0.012 | 4.62 | 100 | 0 |
| | 465.0 | 18 | 1305642 | | 0.015 | 10.88 | 1400 | 6122 |
| | 471.0 | 17 | 4338019 | | 0.017 | 14.15 | 4000 | 18369 |
| | 478.5 | 21 | 1550233 | | 0.016 | 16.93 | 3800 | 7217 |
| | 478.5 | 22 | 1450785 | | 0.013 | 16.77 | 3800 | 7843 |
| | 487.5 | 20 | 242953 | 619189 | 0.015 | 20.67 | 2800 | 1204 |
| | 494.5 | 25 | 783977 | | 0.018 | 19.24 | 3100 | 3226 |
| | 500.5 | 24 | 1180143 | | 0.012 | 18.80 | 4200 | 7589 |
| | 507.0 | 23 | 1522689 | | 0.015 | 21.63 | 5200 | 7602 |
| | 514.5 | 27 | 615181 | | 0.016 | 19.85 | 2600 | 2937 |
| | 523.5 | 26 | 390167 | | 0.017 | 20.89 | 3400 | 1695 |
| | 532.0 | 29 | 182323 | | 0.018 | 23.30 | 1400 | 797 |
| | 541.0 | 28 | 174523 | | 0.016 | 21.07 | 1800 | 853 |
| | 555.0 | 30 | 60965 | 64073 | 0.019 | 21.37 | 820 | 260 |
| | 569.0 | 32 | 236495 | | 0.016 | 19.48 | 600 | 1095 |
| | 569.0 | 33 | 127894 | | 0.012 | 22.70 | 600 | 867 |
| | 578.0 | 31 | 16325 | | 0.017 | 21.28 | 340 | 89 |
| | 586.5 | 35 | 0 | | 0.012 | 23.29 | 60 | 0 |
| | 595.5 | 34 | 0 | | 0.015 | 22.28 | 70 | 0 |
| 12-AB | 424.0 | 37 | 0 | | 0.013 | 2.29 | 0 | 0 |
| | 433.0 | 36 | 0 | | 0.012 | 3.60 | 20 | 0 |
| | 484.0 | 39 | 38057 | | 0.019 | 22.15 | 660 | 163 |
| | 493.0 | 38 | 295690 | | 0.014 | 23.81 | 820 | 1593 |
| | 544.5 | 41 | 1108724 | | 0.017 | 23.42 | 4400 | 5020 |
| | 553.5 | 40 | 82442 | 81577 | 0.017 | 24.70 | 1700 | 383 |

Plattsburgh Solid Soil Core Data - October 9-13, 1995
Separate Phase Analysis

| Borehole ID | Depth Below Surface (in) | Sample ID | Area | Replicate Area | Mass of Wet Soil (kg) | Mass Moisture Mass Dry Soil (%) | TLV (ppm) | Conc of Sep Phase in Dry Soil (mg/kg) |
|-------------|--------------------------|-----------|---------|----------------|-----------------------|---------------------------------|-----------|---------------------------------------|
| 12-AD | 4.5 | 43 | 0 | | 0.012 | 5.93 | 0 | 0 |
| | 4.5 | 44 | 0 | | 0.010 | 6.90 | 0 | 0 |
| | 13.5 | 42 | 0 | | 0.015 | 6.86 | 30 | 0 |
| | 74.5 | 196 | 0 | | 0.011 | 11.21 | 0 | 0 |
| | 134.5 | 46 | 0 | | 0.014 | 2.46 | 10 | 0 |
| | 194.5 | 197 | 0 | | 0.012 | 5.41 | 0 | 0 |
| | 252.5 | 48 | 0 | | 0.014 | 5.86 | 0 | 0 |
| | 314.5 | 49 | 0 | | 0.013 | 8.03 | 0 | 0 |
| | 374.5 | 50 | 0 | 0 | 0.012 | 2.35 | 0 | 0 |
| | 435.0 | 51 | 0 | | 0.014 | 2.14 | 10 | 0 |
| | 442.5 | 53 | 2854 | | 0.011 | 2.22 | 10 | 38 |
| | 458.0 | 57 | 9318 | | 0.011 | 5.52 | 100 | 78 |
| | 463.5 | 56 | 467547 | | 0.015 | 12.69 | 340 | 2154 |
| | 470.5 | 54 | 3746236 | | 0.014 | 20.77 | 2600 | 19535 |
| | 470.5 | 55 | 3877073 | | 0.017 | 20.87 | 2600 | 16679 |
| | 476.0 | 60 | 1074210 | 19769352 | 0.013 | 12.96 | 1600 | 5795 |
| | 481.5 | 59 | 2169205 | | 0.017 | 14.03 | 4000 | 9333 |
| | 488.5 | 58 | 2586528 | | 0.017 | 19.69 | 3400 | 11423 |
| | 501.0 | 61 | 1997565 | | 0.016 | 23.14 | 3000 | 9580 |
| | 514.0 | 64 | 0 | | 0.014 | 17.92 | 120 | 0 |
| | 522.0 | 63 | 0 | | 0.015 | 21.00 | 60 | 0 |
| | 530.0 | 62 | 0 | | 0.018 | 20.34 | 120 | 0 |
| | 541.0 | 67 | 0 | | 0.017 | 22.21 | 40 | 0 |
| | 553.0 | 65 | 3941 | | 0.018 | 17.92 | 40 | 32 |
| | 553.0 | 66 | 0 | | 0.013 | 20.77 | 40 | 0 |
| 12-AG | 2.0 | 70 | 0 | 0 | 0.009 | 4.73 | 50 | 0 |
| | 7.5 | 69 | 0 | | 0.015 | 5.99 | 50 | 0 |
| | 14.5 | 68 | 0 | | 0.014 | 7.40 | 40 | 0 |
| | 75.0 | 71 | 0 | | 0.013 | 5.98 | 60 | 0 |
| | 134.5 | 72 | 0 | | 0.014 | 3.70 | 40 | 0 |
| | 194.5 | 73 | 0 | | 0.013 | 7.54 | 50 | 0 |
| | 252.5 | 74 | 0 | | 0.013 | 4.03 | 60 | 0 |
| | 315.0 | 75 | 0 | | 0.013 | 5.55 | 50 | 0 |
| | 375.0 | 76 | 0 | | 0.012 | 1.05 | 50 | 0 |
| | 375.0 | 77 | 0 | | 0.014 | 1.18 | 50 | 0 |
| | 435.0 | 78 | 0 | | 0.013 | 2.75 | 50 | 0 |
| | 440.0 | 81 | 0 | | 0.014 | 5.34 | 40 | 0 |
| | 445.5 | 80 | 0 | 0 | 0.014 | 2.54 | 50 | 0 |
| | 452.5 | 79 | 0 | | 0.012 | 2.65 | 50 | 0 |
| | 463.5 | 83 | 4237 | | 0.012 | 4.11 | 80 | 42 |
| | 470.5 | 82 | 374789 | | 0.016 | 14.66 | 520 | 1716 |
| | 477.0 | 88 | 2006547 | | 0.018 | 15.58 | 2900 | 8243 |
| | 477.0 | 87 | 1756838 | | 0.016 | 15.27 | 2900 | 7701 |
| | 483.0 | 86 | 2276692 | | 0.014 | 18.51 | 5800 | 12226 |
| | 489.0 | 85 | 2199815 | | 0.016 | 20.90 | 4600 | 10184 |
| | 494.5 | 91 | 2544488 | | 0.017 | 18.64 | 5600 | 11092 |
| | 501.0 | 90 | 4051521 | 3562875 | 0.018 | 19.91 | 5400 | 16364 |
| | 507.5 | 89 | 2572653 | | 0.017 | 22.41 | 4700 | 11444 |
| | 508.0 | 84 | 0 | | 0.013 | 3.42 | 60 | 0 |
| | 522.0 | 92 | 10439 | | 0.018 | 23.46 | 270 | 62 |
| | 539.0 | 94 | 0 | | 0.014 | 19.38 | 50 | 0 |
| | 551.0 | 93 | 0 | | 0.016 | 18.94 | 90 | 0 |

Plattsburgh Solid Soil Core Data - October 9-13, 1995
Separate Phase Analysis

| Borehole ID | Depth Below | Sample ID | Area | Replicate Area | Mass of Wet Soil (kg) | Mass Moisture | TLV (ppm) | Conc of Sep |
|----------------|-----------------|--------------|---------|-------------------|-----------------------------|----------------------|--------------|---------------------------------|
| | Surface (in) | | | | | Mass Dry Soil (%) | | Phase in Dry Soil (mg/kg) |
| 12-AK | 3.0 | 199 | 0 | | 0.007 | 6.39 | 0 | 0 |
| | 9.0 | 198 | 0 | | 0.013 | 4.35 | 0 | 0 |
| | 15.0 | 95 | 0 | | 0.014 | 5.60 | 20 | 0 |
| | 27.0 | 98 | 0 | | 0.015 | 5.27 | 20 | 0 |
| | 74.5 | 99 | 0 | | 0.012 | 8.68 | 40 | 0 |
| | 74.5 | 100 | 0 | 0 | 0.017 | 6.13 | 40 | 0 |
| | 134.5 | 101 | 0 | | 0.017 | 6.53 | 40 | 0 |
| | 194.0 | 102 | 0 | | 0.013 | 1.40 | 0 | 0 |
| | 253.0 | 103 | 0 | | 0.014 | 8.18 | 0 | 0 |
| | 309.0 | 104 | 0 | | 0.013 | 2.03 | 70 | 0 |
| | 375.0 | 105 | 0 | | 0.013 | 4.26 | 60 | 0 |
| | 435.0 | 106 | 1433 | | 0.011 | 1.33 | 270 | 30 |
| | 442.5 | 108 | 483935 | | 0.014 | 1.82 | 800 | 2230 |
| | 451.5 | 107 | 598974 | | 0.012 | 1.86 | 660 | 3212 |
| | 461.5 | 110 | 387540 | 411463 | 0.014 | 2.69 | 1100 | 1796 |
| | 470.5 | 109 | 191709 | | 0.015 | 11.10 | 1200 | 882 |
| | 477.0 | 114 | 1538525 | | 0.016 | 16.74 | 3400 | 7083 |
| | 483.0 | 112 | 3076818 | | 0.016 | 18.10 | 5000 | 14186 |
| | 483.0 | 113 | 2982004 | | 0.018 | 18.64 | 5000 | 12191 |
| | 489.0 | 111 | 1546875 | | 0.016 | 22.94 | 5500 | 7337 |
| | 495.0 | 118 | 1859796 | | 0.018 | 22.46 | 4800 | 7933 |
| | 501.0 | 117 | 2718315 | | 0.018 | 11.85 | 3400 | 10467 |
| | 507.0 | 116 | 40996 | | 0.015 | 21.01 | 560 | 223 |
| | 513.0 | 115 | 6743 | | 0.015 | 21.70 | 500 | 52 |
| | 519.0 | 122 | 9903 | | 0.017 | 20.69 | 320 | 59 |
| | 525.0 | 121 | 0 | | 0.018 | 20.65 | 110 | 0 |
| | 531.0 | 120 | 0 | 0 | 0.016 | 20.73 | 140 | 0 |
| | 537.0 | 119 | 0 | | 0.017 | 22.83 | 220 | 0 |
| | 544.0 | 126 | 0 | | 0.014 | 18.77 | 120 | 0 |
| | 552.0 | 125 | 0 | | 0.017 | 19.99 | 60 | 0 |
| | 560.0 | 123 | 0 | | 0.017 | 22.40 | 80 | 0 |
| | 560.0 | 124 | 0 | | 0.017 | 22.54 | 80 | 0 |
| 12-AM | 422.0 | 129 | 0 | | 0.013 | 2.03 | 10 | 0 |
| | 427.5 | 128 | 0 | | 0.011 | 2.54 | 10 | 0 |
| | 434.5 | 127 | 0 | | 0.013 | 1.74 | 20 | 0 |
| | 442.0 | 132 | 0 | | 0.015 | 2.58 | 20 | 0 |
| | 448.5 | 131 | 0 | | 0.014 | 2.91 | 20 | 0 |
| | 453.5 | 130 | 0 | 0 | 0.014 | 3.46 | 20 | 0 |
| | 458.0 | 136 | 28943 | | 0.013 | 5.02 | 190 | 161 |
| | 464.0 | 134 | 353042 | | 0.016 | 9.68 | 930 | 1498 |
| | 464.0 | 135 | 380821 | | 0.016 | 13.05 | 930 | 1689 |
| | 471.0 | 133 | 3755490 | | 0.016 | 16.52 | 3000 | 16795 |
| | 477.0 | 139 | 837336 | | 0.016 | 15.13 | 3600 | 3683 |
| | 483.0 | 138 | 2572739 | | 0.018 | 16.59 | 4600 | 10651 |
| | 489.0 | 137 | 2266576 | | 0.016 | 20.30 | 3600 | 10434 |
| | 496.0 | 142 | 1555272 | | 0.016 | 20.74 | 5400 | 7529 |
| | 504.0 | 141 | 2937909 | | 0.016 | 19.07 | 5800 | 13615 |
| | 512.0 | 140 | 275492 | 392204 | 0.017 | 20.08 | 2200 | 1253 |
| | 520.0 | 145 | 755908 | | 0.016 | 20.85 | 2200 | 3463 |
| | 520.0 | 146 | 166516 | | 0.007 | 22.57 | 2200 | 1780 |
| | 528.0 | 144 | 2839 | | 0.017 | 20.27 | 320 | 29 |
| | 536.0 | 143 | 0 | | 0.016 | 21.27 | 120 | 0 |
| | 546.0 | 148 | 2048 | | 0.014 | 22.60 | 70 | 33 |
| | 558.0 | 147 | 0 | | 0.016 | 20.88 | 10 | 0 |

Plattsburgh Solid Soil Core Data - October 9-13, 1995
Separate Phase Analysis

| Borehole ID | Depth Below Surface (in) | Sample ID | Area | Replicate Area | Mass of Wet Soil (kg) | Mass Moisture Mass Dry Soil (%) | TLV (ppm) | Conc of Sep Phase in Dry Soil (mg/kg) |
|-------------|--------------------------|-----------|---------|----------------|-----------------------|------------------------------------|-----------|---------------------------------------|
| Control | 15.0 | 200 | 0 | 0 | 0.010 | 2.74 | 0 | 0 |
| | 75.0 | 202 | 0 | | 0.014 | 7.46 | 0 | 0 |
| | 75.0 | 151 | 0 | | 0.012 | 6.89 | 0 | 0 |
| | 134.5 | 203 | 0 | | 0.013 | 5.17 | 0 | 0 |
| | 194.5 | 204 | 0 | | 0.012 | 3.47 | 0 | 0 |
| | 252.5 | 154 | 0 | | 0.013 | 1.22 | 0 | 0 |
| | 309.0 | 155 | 0 | | 0.013 | 15.27 | 10 | 0 |
| | 322.5 | 157 | 0 | | 0.011 | 22.90 | 10 | 0 |
| | 331.5 | 156 | 0 | | 0.016 | 20.28 | 0 | 0 |
| 12-AR | 422.0 | 160 | 0 | 0 | 0.012 | 2.14 | 30 | 0 |
| | 427.5 | 159 | 0 | | 0.010 | 2.05 | 40 | 0 |
| | 434.5 | 158 | 0 | | 0.013 | 2.60 | 40 | 0 |
| | 440.0 | 164 | 0 | | 0.012 | 2.82 | 280 | 0 |
| | 445.5 | 163 | 46308 | | 0.013 | 7.66 | 600 | 250 |
| | 452.5 | 162 | 826529 | | 0.011 | 15.79 | 1900 | 5648 |
| | 452.5 | 161 | 618958 | | 0.014 | 16.06 | 1900 | 3168 |
| | 459.0 | 167 | 626508 | | 0.012 | 10.11 | 4000 | 3699 |
| | 465.0 | 166 | 2453906 | | 0.018 | 19.53 | 6000 | 10427 |
| | 471.0 | 165 | 2137463 | | 0.016 | 19.40 | 5200 | 9672 |
| | 477.0 | 170 | 3375813 | 3082126 | 0.017 | 18.03 | 5200 | 14864 |
| | 483.0 | 169 | 1740299 | | 0.017 | 18.17 | 4900 | 7571 |
| | 489.0 | 168 | 2226897 | | 0.018 | 19.32 | 4700 | 9330 |
| | 496.0 | 174 | 805140 | | 0.015 | 17.81 | 4200 | 3834 |
| | 504.0 | 172 | 19664 | | 0.015 | 14.45 | 380 | 109 |
| | 504.0 | 173 | 5877 | | 0.014 | 13.51 | 380 | 47 |
| | 512.0 | 171 | 1574 | | 0.014 | 19.86 | 280 | 28 |
| | 522.0 | 176 | 15375 | | 0.014 | 18.33 | 1000 | 99 |
| | 528.0 | 175 | 2199 | | 0.015 | 21.34 | 100 | 29 |
| | 546.0 | 178 | 0 | | 0.015 | 19.45 | 800 | 0 |
| | 558.0 | 177 | 0 | | 0.016 | 21.50 | 60 | 0 |

Plattsburgh Solid Soil Core Data - October 9-13, 1995
Separate Phase Analysis

| Borehole ID | Depth Below | Sample ID | Area | Replicate Area | Mass of Wet Soil (kg) | Mass Moisture | TLV (ppm) | Conc of Sep |
|--------------|--------------|-----------|---------|----------------|-----------------------|-------------------|-----------|---------------------------|
| | Surface (in) | | | | | Mass Dry Soil (%) | | Phase in Dry Soil (mg/kg) |
| 12-A_P | 423.0 | 181 | 0 | 0 | 0.011 | 4.46 | 100 | 0 |
| | 428.5 | 180 | 0 | | 0.013 | 2.10 | 60 | 0 |
| | 434.5 | 179 | 0 | | 0.013 | 2.26 | 100 | 0 |
| | 440.0 | 185 | 0 | | 0.011 | 3.59 | 50 | 0 |
| | 446.0 | 183 | 0 | | 0.014 | 2.26 | 100 | 0 |
| | 453.0 | 182 | 0 | | 0.011 | 3.00 | 180 | 0 |
| | 459.0 | 188 | 0 | | 0.012 | 4.19 | 420 | 0 |
| | 471.0 | 184 | 0 | | 0.015 | 2.95 | 100 | 0 |
| | 477.0 | 191 | 1461446 | 2676938 | 0.015 | 16.19 | 6400 | 7121 |
| | 480.0 | 186 | 2302759 | | 0.017 | 17.04 | 4400 | 9750 |
| | 483.0 | 190 | 2574952 | | 0.015 | 16.93 | 5300 | 12131 |
| | 483.0 | 187 | 654569 | | 0.015 | 13.70 | 1500 | 3102 |
| | 489.0 | 189 | 2135038 | | 0.017 | 21.05 | 5400 | 9345 |
| | 498.0 | 193 | 112929 | | 0.007 | 18.29 | 3600 | 1168 |
| | 510.0 | 192 | 5749 | | 0.014 | 17.28 | 460 | 48 |
| | 522.0 | 195 | 11913 | | 0.012 | 16.72 | 1600 | 98 |
| | 534.0 | 194 | 0 | | 0.011 | 17.99 | 220 | 0 |
| | | | | | | | | |
| Field Spikes | | | | | | | | |
| 12-AD | 74.5 | 45 | 698788 | | | | | |
| 12-AD | 194.5 | 47 | 1552176 | | | | | |
| 12-AK | 9.0 | 96 | 2660374 | | | | | |
| 12-AK | 3.0 | 97 | 2142122 | | | | | |
| Control | 15.0 | 149 | 758642 | | | | | |
| Control | 75.0 | 150 | 1298716 | | | | | |
| Control | 134.5 | 152 | 2188391 | | | | | |
| Control | 194.5 | 153 | 2631153 | | | | | |

Plattsburgh Solid Soil Core Data - Nov. 30 - Dec. 2, 1995
Separate Phase Analysis

| Borehole ID | Depth Below Surface (in) | Sample ID | Area | Replicate Area | Mass of Wet Soil (kg) | Mass Moisture Mass Dry Soil (%) | TLV (ppm) | Conc of Sep Phase in Dry Soil (mg/kg) |
|-------------|--------------------------|-----------|---------|----------------|-----------------------|------------------------------------|-----------|---------------------------------------|
| VENT 1 | 420.5 | 10 | 0 | 0 | 0.013 | 5.16 | 10 | 0 |
| | 420.5 | 11 | 0 | | 0.013 | 4.81 | 10 | 0 |
| | 421.5 | 9 | 0 | | 0.011 | 7.59 | 0 | 0 |
| | 423 | 8 | 0 | | 0.012 | 2.97 | 10 | 0 |
| | 425 | 7 | 0 | | 0.012 | 3.20 | 0 | 0 |
| | 427 | 6 | 0 | | 0.014 | 3.40 | 0 | 0 |
| | 429 | 5 | 0 | | 0.012 | 2.62 | 0 | 0 |
| | 431 | 4 | 0 | | 0.010 | 2.93 | 0 | 0 |
| | 433 | 3 | 0 | | 0.010 | 2.70 | 0 | 0 |
| | 435 | 2 | 0 | | 0.016 | 2.73 | 0 | 0 |
| | 437 | 1 | 0 | | 0.013 | 2.56 | 0 | 0 |
| | 438.5 | 23 | 0 | | 0.011 | 3.80 | 0 | 0 |
| | 439.5 | 22 | 0 | | 0.014 | 3.15 | 0 | 0 |
| | 439.5 | 21 | 0 | | 0.013 | 3.17 | 0 | 0 |
| | 440.5 | 20 | 0 | 0 | 0.014 | 2.81 | 10 | 0 |
| | 441.5 | 19 | 0 | | 0.014 | 2.77 | 0 | 0 |
| | 443 | 18 | 0 | | 0.014 | 2.65 | 10 | 0 |
| | 445 | 17 | 0 | | 0.014 | 2.65 | 0 | 0 |
| | 447 | 16 | 0 | | 0.014 | 2.52 | 10 | 0 |
| | 449 | 15 | 0 | | 0.010 | 2.66 | 0 | 0 |
| | 451 | 14 | 0 | | 0.011 | 3.03 | 0 | 0 |
| | 453 | 13 | 0 | | 0.014 | 2.97 | 0 | 0 |
| | 455 | 12 | 0 | | 0.010 | 3.32 | 20 | 0 |
| | 457 | 32 | 0 | | 0.012 | 3.56 | 10 | 0 |
| | 457 | 33 | 0 | | 0.011 | 3.19 | 10 | 0 |
| | 459 | 31 | 0 | | 0.012 | 1.62 | 10 | 0 |
| | 461 | 30 | 0 | 0 | 0.014 | 2.44 | 10 | 0 |
| | 463 | 29 | 0 | | 0.016 | 3.25 | 0 | 0 |
| | 465 | 28 | 0 | | 0.008 | 2.64 | 0 | 0 |
| | 467 | 27 | 0 | | 0.013 | 7.13 | 0 | 0 |
| | 469 | 26 | 0 | | 0.015 | 11.28 | 10 | 0 |
| | 471 | 25 | 0 | | 0.013 | 13.87 | 10 | 0 |
| | 473 | 24 | 11592 | | 0.014 | 14.79 | 10 | 165 |
| | 475 | 41 | 0 | | 0.012 | 18.71 | 30 | 0 |
| | 477.5 | 40 | 0 | 0 | 0.016 | 17.90 | 60 | 0 |
| | 480 | 39 | 0 | | 0.017 | 19.52 | 100 | 0 |
| | 482 | 38 | 59997 | | 0.018 | 18.65 | 3400 | 345 |
| | 484 | 37 | 2414821 | | 0.013 | 19.02 | 2900 | 14184 |
| | 486 | 36 | 5054119 | | 0.031 | 20.55 | 2800 | 12895 |
| | 488 | 35 | 3378201 | | 0.018 | 21.23 | 2600 | 15166 |
| | 490.5 | 34 | 2991441 | | 0.015 | 20.50 | 2200 | 15613 |
| | 493 | 49 | 9943 | | 0.019 | 19.79 | 70 | 120 |
| | 498 | 48 | 46106 | | 0.014 | 18.70 | 900 | 374 |
| | 500 | 47 | 2321683 | | 0.019 | 18.49 | 1800 | 9714 |
| | 502 | 46 | 1800893 | | 0.018 | 19.95 | 2700 | 7738 |
| | 504 | 45 | 3404974 | | 0.018 | 20.11 | 2700 | 14496 |
| | 506 | 43 | 3190930 | | 0.019 | 19.94 | 2500 | 13262 |
| | 506 | 44 | 2226882 | | 0.017 | 19.84 | 2500 | 10219 |
| | 508.5 | 42 | 2367055 | | 0.017 | 22.00 | 3200 | 10944 |

Plattsburgh Solid Soil Core Data - Nov. 30 - Dec. 2, 1995
 Separate Phase Analysis

| Borehole ID | Depth Below Surface (in) | Sample ID | Area | Replicate Area | Mass of Wet Soil (kg) | Mass Moisture Mass Dry Soil (%) | TLV (ppm) | Conc of Sep Phase in Dry Soil (mg/kg) |
|-------------|--------------------------|-----------|---------|----------------|-----------------------|---------------------------------|-----------|---------------------------------------|
| VENT 2 | 422 | 276 | 0 | 0 | 0.013 | 10.69 | 0 | 0 |
| | 427.5 | 275 | 0 | | 0.013 | 5.82 | 0 | 0 |
| | 434.5 | 50 | 0 | | 0.011 | 3.25 | 0 | 0 |
| | 440 | 56 | 0 | | 0.013 | 10.02 | 0 | 0 |
| | 445.5 | 55 | 0 | | 0.014 | 5.37 | 0 | 0 |
| | 452.5 | 53 | 0 | | 0.014 | 3.51 | 0 | 0 |
| | 452.5 | 54 | 0 | | 0.013 | 3.51 | 0 | 0 |
| | 457 | 65 | 0 | | 0.015 | 5.92 | 0 | 0 |
| | 457 | 64 | 0 | | 0.013 | 6.30 | 0 | 0 |
| | 459.5 | 63 | 0 | | 0.012 | 4.02 | 0 | 0 |
| | 462 | 62 | 0 | | 0.012 | 4.06 | 0 | 0 |
| | 464 | 61 | 0 | | 0.009 | 4.31 | 0 | 0 |
| | 466 | 60 | 321411 | 171744 | 0.016 | 16.32 | 80 | 1611 |
| | 468 | 59 | 605845 | | 0.015 | 18.64 | 900 | 3193 |
| | 470 | 58 | 2374633 | | 0.017 | 18.40 | 1000 | 10811 |
| | 472.5 | 57 | 2348668 | | 0.018 | 18.25 | 1800 | 10352 |
| | 475 | 74 | 6288 | | 0.013 | 11.89 | 80 | 147 |
| | 477 | 73 | 0 | | 0.017 | 14.11 | 80 | 0 |
| | 479 | 72 | 0 | | 0.017 | 16.52 | 80 | 0 |
| | 481 | 71 | 547965 | | 0.017 | 17.39 | 200 | 2554 |
| | 483 | 70 | 2975112 | 2423035 | 0.018 | 17.48 | 2200 | 12823 |
| | 485 | 69 | 1552542 | | 0.016 | 17.00 | 1800 | 7550 |
| | 487 | 68 | 96366 | | 0.016 | 20.06 | 1800 | 551 |
| | 489 | 67 | 22379 | | 0.015 | 20.88 | 300 | 220 |
| | 491 | 66 | 27730 | | 0.018 | 20.60 | 800 | 206 |
| | 496 | 78 | 326369 | | 0.018 | 22.86 | 800 | 1505 |
| | 504 | 77 | 1836054 | | 0.018 | 21.77 | 2000 | 8362 |
| | 512 | 75 | 26420 | | 0.016 | 22.79 | 200 | 225 |
| | 512 | 76 | 25673 | | 0.019 | 22.84 | 200 | 195 |

Plattsburgh Solid Soil Core Data - Nov. 30 - Dec. 2, 1995
 Separate Phase Analysis

| Borehole ID | Depth Below Surface (in) | Sample ID | Area | Replicate Area | Mass of Wet Soil (kg) | Mass Moisture Mass Dry Soil (%) | TLV (ppm) | Conc of Sep Phase In Dry Soil (mg/kg) |
|-------------|--------------------------|-----------|---------|----------------|-----------------------|---------------------------------|-----------|---------------------------------------|
| SPARGE 1 | 421 | 86 | 0 | | 0.013 | 7.44 | 0 | 0 |
| | 423.5 | 85 | 0 | | 0.014 | 7.67 | 0 | 0 |
| | 426 | 84 | 0 | | 0.014 | 3.61 | 0 | 0 |
| | 428 | 278 | 0 | | 0.010 | 4.91 | 0 | 0 |
| | 430 | 277 | 0 | | 0.011 | 2.63 | 0 | 0 |
| | 432 | 81 | 0 | | 0.014 | 2.65 | 0 | 0 |
| | 434 | 80 | 0 | 0 | 0.013 | 3.03 | 0 | 0 |
| | 436.5 | 79 | 0 | | 0.013 | 2.23 | 0 | 0 |
| | 438.5 | 97 | 0 | | 0.010 | 10.71 | 0 | 0 |
| | 439.5 | 96 | 0 | | 0.015 | 9.82 | 0 | 0 |
| | 441 | 95 | 0 | | 0.015 | 7.40 | 0 | 0 |
| | 443 | 94 | 0 | | 0.013 | 5.92 | 0 | 0 |
| | 445 | 93 | 0 | | 0.015 | 4.61 | 0 | 0 |
| | 447 | 92 | 0 | | 0.013 | 3.02 | 0 | 0 |
| | 449 | 91 | 0 | | 0.014 | 2.84 | 0 | 0 |
| | 451 | 90 | 0 | 0 | 0.014 | 3.01 | 0 | 0 |
| | 453 | 89 | 0 | | 0.013 | 3.69 | 0 | 0 |
| | 453 | 88 | 0 | | 0.014 | 3.70 | 0 | 0 |
| | 455 | 87 | 0 | | 0.015 | 3.43 | 0 | 0 |
| | 457 | 107 | 0 | | 0.014 | 9.77 | 0 | 0 |
| | 459 | 106 | 0 | | 0.015 | 6.94 | 0 | 0 |
| | 461 | 105 | 0 | | 0.014 | 4.66 | 0 | 0 |
| | 463 | 104 | 0 | | 0.015 | 2.89 | 20 | 0 |
| | 465 | 103 | 11044 | | 0.015 | 6.44 | 20 | 144 |
| | 467 | 102 | 518556 | | 0.017 | 17.04 | 60 | 2459 |
| | 469 | 101 | 243701 | | 0.017 | 17.56 | 100 | 1191 |
| | 471 | 100 | 278967 | 252516 | 0.016 | 18.68 | 1000 | 1425 |
| | 471 | 99 | 275022 | | 0.017 | 18.24 | 1000 | 1358 |
| | 473 | 98 | 2168262 | | 0.018 | 18.15 | 2000 | 9464 |
| | 475 | 117 | 0 | | 0.014 | 10.12 | 60 | 0 |
| | 477 | 116 | 0 | | 0.019 | 14.24 | 120 | 0 |
| | 479 | 115 | 0 | | 0.017 | 18.04 | 100 | 0 |
| | 481 | 114 | 7188 | | 0.016 | 19.05 | 240 | 127 |
| | 483 | 113 | 453374 | | 0.017 | 17.50 | 1200 | 2112 |
| | 485 | 112 | 2836379 | | 0.020 | 19.25 | 3800 | 11213 |
| | 487 | 111 | 465789 | | 0.017 | 20.73 | 2800 | 2210 |
| | 487 | 110 | 718797 | 735451 | 0.017 | 22.62 | 2800 | 3475 |
| | 489 | 109 | 959133 | | 0.016 | 21.06 | 1700 | 4712 |
| | 491 | 108 | 1634453 | | 0.019 | 21.47 | 1800 | 6829 |
| | 493 | 125 | 51125 | | 0.023 | 21.88 | 120 | 242 |
| | 495 | 124 | 71574 | | 0.018 | 20.07 | 190 | 395 |
| | 497 | 122 | 70085 | | 0.017 | 19.94 | 400 | 401 |
| | 497 | 123 | 149420 | | 0.017 | 19.10 | 400 | 770 |
| | 499.5 | 121 | 1436937 | | 0.017 | 20.00 | 620 | 6713 |
| | 502.5 | 120 | 2604494 | 2791875 | 0.018 | 21.13 | 1500 | 11431 |
| | 505.5 | 119 | 3255408 | | 0.017 | 21.94 | 2200 | 15623 |
| | 508.5 | 118 | 2332817 | | 0.019 | 21.86 | 2400 | 10032 |
| | 511.5 | 130 | 72387 | 31135 | 0.017 | 19.71 | 0 | 422 |
| | 514.5 | 129 | 92864 | | 0.018 | 18.53 | 30 | 473 |
| | 518 | 128 | 90162 | | 0.018 | 18.51 | 30 | 466 |
| | 522 | 127 | 113198 | | 0.018 | 21.03 | 120 | 572 |
| | 526 | 126 | 0 | | 0.017 | 22.38 | 20 | 0 |
| | 530 | 135 | 46892 | | 0.016 | 20.06 | 0 | 334 |
| | 534 | 134 | 10899 | | 0.015 | 18.34 | 0 | 155 |
| | 538.5 | 133 | 46430 | | 0.018 | 18.29 | 0 | 275 |
| | 538.5 | 132 | 31359 | | 0.017 | 78.87 | 0 | 340 |
| | 543.5 | 131 | 140536 | | 0.017 | 21.02 | 80 | 722 |
| | 547.5 | 141 | 33794 | | 0.013 | 25.02 | 10 | 329 |
| | 550.5 | 140 | 24249 | 22559 | 0.017 | 18.28 | 90 | 194 |
| | 553.5 | 139 | 26031 | | 0.016 | 18.09 | 60 | 214 |
| | 556.5 | 138 | 87594 | | 0.018 | 20.91 | 150 | 463 |
| | 559.5 | 137 | 23128 | | 0.013 | 21.77 | 20 | 265 |
| | 562.5 | 136 | 1498 | | 0.019 | 23.79 | 0 | 89 |
| | 566 | 147 | 47928 | | 0.016 | 19.65 | 280 | 322 |
| | 566 | 148 | 15169 | | 0.016 | 19.55 | 280 | 166 |
| | 570 | 146 | 151189 | | 0.015 | 18.15 | 340 | 880 |
| | 574 | 145 | 186173 | | 0.017 | 20.10 | 180 | 953 |
| | 578 | 144 | 23253 | | 0.011 | 23.12 | 280 | 310 |
| | 582 | 143 | 3178 | | 0.019 | 31.93 | 180 | 102 |
| | 586 | 142 | 0 | | 0.014 | 31.93 | 20 | 0 |

Plattsburgh Solid Soil Core Data - Nov. 30 - Dec. 2, 1995
Separate Phase Analysis

| Borehole ID | Depth Below Surface (in) | Sample ID | Area | Replicate Area | Mass of Wet Soil (kg) | Mass Moisture Mass Dry Soil (%) | TLV (ppm) | Conc of Sep Phase in Dry Soil (mg/kg) |
|-------------|--------------------------|-----------|---------|----------------|-----------------------|------------------------------------|-----------|---------------------------------------|
| 12-AS | 421.5 | 282 | 0 | | 0.018 | 14.99 | 0 | 0 |
| | 427 | 281 | 0 | | 0.015 | 7.01 | 0 | 0 |
| | 429 | 213 | 0 | | 0.014 | 2.08 | 0 | 0 |
| | 431 | 280 | 0 | 0 | 0.012 | 2.20 | 0 | 0 |
| | 433 | 211 | 0 | | 0.013 | 2.29 | 0 | 0 |
| | 435 | 279 | 0 | | 0.011 | 2.65 | 0 | 0 |
| | 437 | 209 | 0 | | 0.014 | 3.13 | 0 | 0 |
| | 439 | 225 | 0 | | 0.016 | 7.71 | 0 | 0 |
| | 441 | 224 | 0 | | 0.014 | 3.25 | 0 | 0 |
| | 443 | 223 | 0 | | 0.015 | 6.40 | 10 | 0 |
| | 445 | 222 | 0 | | 0.014 | 3.14 | 0 | 0 |
| | 447 | 221 | 0 | | 0.013 | 2.64 | 20 | 0 |
| | 449 | 220 | 0 | 0 | 0.011 | 2.77 | 30 | 0 |
| | 451.5 | 218 | 102594 | | 0.014 | 7.98 | 100 | 602 |
| | 454.5 | 217 | 244410 | | 0.014 | 14.58 | 100 | 1420 |
| | 457 | 235 | 0 | | 0.017 | 6.22 | 40 | 0 |
| | 459 | 234 | 0 | | 0.016 | 6.04 | 60 | 0 |
| | 461 | 233 | 174407 | | 0.018 | 15.70 | 120 | 824 |
| | 463 | 232 | 361357 | | 0.017 | 18.22 | 240 | 1703 |
| | 465 | 230 | 250611 | 236535 | 0.017 | 19.64 | 300 | 1220 |
| | 465 | 231 | 308302 | | 0.016 | 18.26 | 300 | 1618 |
| | 467 | 229 | 2114501 | | 0.016 | 17.84 | 1400 | 10284 |
| | 469 | 228 | 5920009 | | 0.017 | 18.10 | 2600 | 26335 |
| | 471 | 227 | 3851366 | | 0.017 | 19.67 | 2200 | 17593 |
| | 473 | 226 | 3050885 | | 0.017 | 17.98 | 2000 | 14021 |
| | 475 | 245 | 3387306 | | 0.018 | 17.77 | 2800 | 14241 |
| | 477 | 244 | 1130388 | | 0.018 | 15.15 | 2200 | 4917 |
| | 479 | 243 | 1257685 | | 0.017 | 14.55 | 1800 | 5586 |
| | 481 | 241 | 3385903 | | 0.016 | 15.86 | 3200 | 15796 |
| | 481 | 242 | 2527829 | | 0.017 | 15.76 | 3200 | 11226 |
| | 483 | 240 | 2851620 | 3168876 | 0.018 | 17.64 | 2000 | 12536 |
| | 485 | 239 | 2596824 | | 0.017 | 19.79 | 2600 | 12087 |
| | 487 | 238 | 2235215 | | 0.017 | 20.63 | 3200 | 10514 |
| | 489 | 237 | 3351756 | | 0.018 | 22.16 | 3000 | 15078 |
| | 491 | 236 | 2433956 | | 0.018 | 23.69 | 3200 | 11086 |
| | 493 | 254 | 849273 | | 0.017 | 21.32 | 2200 | 4032 |
| | 495.5 | 253 | 929003 | | 0.017 | 18.83 | 1500 | 4311 |
| | 495.5 | 252 | 1313418 | | 0.018 | 19.91 | 1500 | 5689 |
| | 498 | 251 | 895440 | | 0.012 | 19.15 | 2600 | 5739 |
| | 500 | 250 | 1498019 | 1198899 | 0.015 | 19.98 | 4000 | 7697 |
| | 502 | 249 | 2708365 | | 0.018 | 20.64 | 2600 | 12228 |
| | 504 | 248 | 947555 | | 0.017 | 21.99 | 1600 | 4414 |
| | 506 | 247 | 259762 | | 0.013 | 24.08 | 200 | 1694 |
| | 508.5 | 246 | 517489 | | 0.019 | 22.94 | 700 | 2285 |
| | 511.5 | 259 | 1312746 | | 0.019 | 22.03 | 200 | 5644 |
| | 514 | 258 | 289127 | | 0.018 | 20.79 | 650 | 1360 |
| | 518 | 257 | 1296582 | | 0.018 | 22.38 | 900 | 5701 |
| | 522 | 256 | 373117 | | 0.019 | 24.03 | 380 | 1678 |
| | 526 | 255 | 0 | | 0.018 | 22.59 | 250 | 0 |
| | 531 | 262 | 244596 | | 0.019 | 24.64 | 80 | 1129 |
| | 537 | 261 | 136006 | | 0.018 | 24.71 | 150 | 688 |
| | 543 | 260 | 98368 | 102537 | 0.017 | 24.04 | 180 | 572 |
| | 549 | 267 | 57614 | | 0.016 | 20.72 | 40 | 383 |
| | 555 | 266 | 77864 | | 0.017 | 20.55 | 220 | 458 |
| | 561 | 265 | 69725 | | 0.017 | 20.81 | 340 | 418 |
| | 567 | 264 | 12626 | | 0.016 | 22.30 | 60 | 165 |
| | 567 | 263 | 13294 | | 0.017 | 21.96 | 60 | 153 |
| | 572 | 273 | 5666 | | 0.017 | 22.09 | 40 | 116 |
| | 572 | 274 | 0 | | 0.013 | 22.09 | 40 | 0 |
| | 580 | 271 | 2250 | | 0.017 | 19.75 | 40 | 100 |
| | 584 | 270 | 0 | 0 | 0.012 | 20.18 | 10 | 0 |
| | 588 | 269 | 0 | | 0.016 | 20.41 | 20 | 0 |
| | 592 | 268 | 0 | | 0.016 | 20.76 | 20 | 0 |

Plattsburgh Solid Soil Core Data - Nov. 30 - Dec. 2, 1995
Separate Phase Analysis

| Borehole ID | Depth Below Surface (in) | Sample ID | Area | Replicate Area | Mass of Wet Soil (kg) | Mass Moisture Mass Dry Soil (%) | TLV (ppm) | Conc of Sep Phase in Dry Soil (mg/kg) |
|-------------|--------------------------|-----------|------|----------------|-----------------------|---------------------------------|-----------|---------------------------------------|
| 12-AT | 300.5 | 159 | 0 | | 0.016 | 15.28 | 0 | 0 |
| | 300.5 | 158 | 0 | | 0.016 | 15.70 | 0 | 0 |
| | 301.5 | 157 | 0 | | 0.015 | 15.19 | 0 | 0 |
| | 303 | 156 | 0 | | 0.014 | 19.56 | 0 | 0 |
| | 305 | 155 | 0 | | 0.014 | 19.11 | 0 | 0 |
| | 307 | 154 | 0 | | 0.018 | 17.64 | 0 | 0 |
| | 309 | 153 | 0 | | 0.012 | 9.02 | 0 | 0 |
| | 311 | 152 | 0 | | 0.016 | 20.38 | 0 | 0 |
| | 313 | 151 | 0 | | 0.012 | 19.00 | 0 | 0 |
| | 315 | 150 | 0 | 0 | 0.013 | 6.53 | 0 | 0 |
| | 317 | 149 | 0 | | 0.011 | 2.88 | 0 | 0 |
| | 360.5 | 169 | 0 | | 0.014 | 16.64 | 0 | 0 |
| | 361.5 | 168 | 0 | | 0.016 | 15.95 | 0 | 0 |
| | 363 | 167 | 0 | | 0.016 | 20.26 | 0 | 0 |
| | 365 | 166 | 0 | | 0.015 | 18.42 | 0 | 0 |
| | 367 | 165 | 0 | | 0.014 | 12.31 | 0 | 0 |
| | 369 | 164 | 0 | | 0.012 | 7.56 | 0 | 0 |
| | 371 | 163 | 0 | | 0.016 | 15.56 | 0 | 0 |
| | 373 | 162 | 0 | | 0.008 | 7.55 | 0 | 0 |
| | 375 | 161 | 0 | | 0.015 | 13.31 | 0 | 0 |
| | 377 | 160 | 0 | 0 | 0.010 | 14.35 | 0 | 0 |
| | 379 | 178 | 0 | | 0.011 | 15.38 | 10 | 0 |
| | 381 | 177 | 0 | | 0.016 | 10.68 | 10 | 0 |
| | 383 | 176 | 0 | | 0.015 | 7.06 | 0 | 0 |
| | 385 | 175 | 0 | | 0.016 | 16.31 | 0 | 0 |
| | 387 | 174 | 0 | | 0.013 | 11.26 | 0 | 0 |
| | 389.5 | 173 | 0 | | 0.016 | 13.46 | 0 | 0 |
| | 392 | 172 | 0 | | 0.016 | 18.07 | 0 | 0 |
| | 394.5 | 171 | 0 | | 0.015 | 16.96 | 0 | 0 |
| | 394.5 | 170 | 0 | 0 | 0.015 | 16.34 | 0 | 0 |
| | 397 | 186 | 0 | | 0.018 | 24.50 | 130 | 0 |
| | 399.5 | 185 | 0 | | 0.018 | 18.07 | 120 | 0 |
| | 402.5 | 184 | 0 | | 0.018 | 17.70 | 20 | 0 |
| | 405 | 183 | 0 | | 0.016 | 16.91 | 0 | 0 |
| | 407 | 182 | 0 | | 0.017 | 21.00 | 0 | 0 |
| | 407 | 181 | 0 | | 0.017 | 20.60 | 0 | 0 |
| | 409.5 | 180 | 0 | 0 | 0.018 | 23.01 | 10 | 0 |
| | 412.5 | 179 | 0 | | 0.019 | 23.16 | 0 | 0 |
| | 415 | 196 | 0 | | 0.018 | 21.20 | 0 | 0 |
| | 417 | 195 | 0 | | 0.017 | 19.44 | 0 | 0 |
| | 418.5 | 194 | 0 | | 0.016 | 17.57 | 30 | 0 |
| | 419.5 | 193 | 0 | | 0.018 | 19.23 | 20 | 0 |
| | 420.5 | 192 | 0 | | 0.018 | 18.25 | 20 | 0 |
| | 422 | 191 | 0 | | 0.016 | 20.33 | 20 | 0 |
| | 424 | 190 | 0 | 0 | 0.016 | 19.27 | 20 | 0 |
| | 426 | 189 | 0 | | 0.018 | 19.73 | 0 | 0 |
| | 428 | 188 | 0 | | 0.017 | 22.04 | 0 | 0 |
| | 430.5 | 187 | 0 | | 0.019 | 21.40 | 0 | 0 |
| | 432.5 | 207 | 0 | | 0.017 | 24.06 | 0 | 0 |
| | 433.5 | 206 | 0 | | 0.011 | 21.23 | 0 | 0 |
| | 435 | 205 | 0 | | 0.016 | 21.12 | 0 | 0 |
| | 437 | 204 | 0 | | 0.018 | 21.47 | 0 | 0 |
| | 439 | 203 | 0 | | 0.018 | 22.02 | 0 | 0 |
| | 441 | 202 | 0 | | 0.018 | 21.23 | 0 | 0 |
| | 441 | 201 | 0 | | 0.013 | 21.74 | 0 | 0 |
| | 443 | 200 | 0 | | 0.013 | 21.12 | 0 | 0 |
| | 445 | 199 | 0 | | 0.018 | 21.84 | 0 | 0 |
| | 447 | 198 | 0 | | 0.019 | 21.36 | 0 | 0 |
| | 449 | 197 | 0 | | 0.020 | 21.99 | 0 | 0 |
| | 467 | 208 | 0 | | 0.019 | 22.03 | 0 | 0 |

Plattsburgh Solid Core Data-June5-7, 1996
 Separate Phase Analysis-12AU

| Barrel Depth (ft) | Sample Depth (in) | Sample Depth (m) | Jar Number | Vial Number | TLV (ppm) | Moisture Content (%) | HC conc (mg sep. ph./ kg dry soil) | Rep HC Conc (mg/kg) |
|-------------------------|-------------------------|------------------------|---------------|----------------|--------------|----------------------------|--|---------------------------|
| 38.0-39.5 | 456-462 | 459 | 11.7 | 171 | 72 | 0 | 11.1% | 0 |
| | 462-468 | 465 | 11.8 | 170 | 71 | 80 | 15.6% | 0 |
| | 468-474 | 471 | 12.0 | 169 | 70 | 480 | 19.3% | 1111 |
| 39.5-41.0 | 474-480 | 477 | 12.1 | 174 | 75 | 1200 | 16.8% | 4196 |
| | 480-486 | 483 | 12.3 | 173 | 74 | 1800 | 15.7% | 1990 |
| | 486-492 | 489 | 12.4 | 172 | 73 | 3400 | 22.0% | 15976 |
| 41.0-42.5 | 492-510 | | | | | | | |
| 42.5-44.0 | 510-513 | 511 | 13.0 | 4 | 4 | 450 | 21.2% | 196 |
| | 513-518 | 515 | 13.1 | 3 | 3 | 950 | 20.7% | 1756 |
| | 518-523 | 520 | 13.2 | 2 | 2 | 180 | 21.0% | 49 |
| 44.0-45.5 | 523-528 | 526 | 13.4 | 1 | 1 | 60 | 23.0% | 21 |
| | 528-531 | 530 | 13.5 | 8 | 8 | 680 | 20.1% | 360 |
| | 531-536 | 534 | 13.6 | 7 | 7 | 1200 | 19.9% | 1227 |
| 45.5-47.0 | 536-541 | 538 | 13.7 | 6 | 6 | 200 | 20.2% | 58 |
| | 541-546 | 544 | 13.8 | 5 | 5 | 140 | 21.6% | 72 |
| | 546-552 | 549 | 13.9 | 11 | 12 | 220 | 21.6% | 218 |
| R | 552-558 | 555 | 14.1 | 10 | 10 | 100 | 21.9% | 30 |
| | 552-558 | 555 | 14.1 | 10 | 11 | 100 | 20.6% | 29 |
| | 558-564 | 561 | 14.2 | 9 | 9 | 60 | 22.9% | 7 |
| 47.0-49.0 | 564-570 | 567 | 14.4 | 15 | 16 | 200 | 19.5% | 66 |
| | 570-576 | 573 | 14.6 | 14 | 15 | 40 | 19.4% | 1 |
| | 576-582 | 579 | 14.7 | 13 | 14 | 20 | 21.2% | 1 |
| | 582-588 | 585 | 14.9 | 12 | 13 | 30 | 22.4% | 0 |

Plattsburgh Solid Core Data-June5-7, 1996
 Separate Phase Analysis-12AV

| Barrel Depth (ft) | Sample Depth (in) | Sample Depth (m) | Jar Number | Vial Number | TLV (ppm) | Moisture Content (%) | HC conc (mg sep. ph./ kg dry soil) | Rep HC Conc (mg/kg) |
|-------------------------|-------------------------|------------------------|---------------|----------------|--------------|----------------------------|--|---------------------------|
| 35.0-36.5 | 420-422 | 420 | 177 | 79 | 20 | 4.7% | 0 | |
| | 422-430 | 426 | 176 | 77 | 60 | 2.6% | 0 | |
| R | 422-430 | 426 | 176 | 78 | 60 | 2.4% | 0 | |
| | 430-438 | 434 | 175 | 76 | 60 | 3.4% | 0 | |
| 36.5-38.0 | 438-440 | 441 | 18 | 19 | 80 | 5.5% | 1 | |
| | 442-445 | 443 | 17 | 18 | 60 | 4.2% | 5 | |
| | 454-456 | 455 | 16 | 17 | 260 | 20.6% | 4754 | |
| 38.0-39.5 | 456-464 | 459 | 179 | 81 | 260 | 14.6% | 231 | |
| | 464-472 | 467 | 178 | 80 | 1500 | 17.7% | 7324 | 7693 |
| 39.5-41.0 | 474-478 | 476 | 23 | 25 | 1200 | 20.0% | 1669 | |
| | 478-482 | 480 | 22 | 24 | 720 | 17.5% | 3947 | |
| | 482-486 | 484 | 21 | 23 | 1200 | 16.8% | 13814 | |
| | 486-490 | 488 | 20 | 21 | 4400 | 19.6% | 13156 | |
| R | 486-490 | 488 | 20 | 22 | 4400 | 19.7% | 7732 | |
| | 490-492 | 490 | 19 | 20 | 3200 | 22.0% | 4558 | 4495 |
| 41.0-43.0 | 492-498 | 495 | 27 | 29 | 880 | 21.6% | 679 | |
| | 498-504 | 501 | 26 | 28 | 600 | 19.1% | 340 | |
| | 504-510 | 507 | 25 | 27 | 1200 | 18.5% | 1594 | |
| | 510-516 | 513 | 24 | 26 | 1800 | 20% | 3312 | |
| 43.0-45.0 | 516-521 | 518 | 32 | 35 | 520 | 20.0% | 816 | |
| | 521-526 | 523 | 31 | 34 | 1200 | 19.2% | 1691 | |
| | 526-531 | 528 | 30 | 32 | 1600 | 19.6% | 1394 | |
| R | 526-531 | 528 | 30 | 33 | 1600 | 19.4% | 1293 | |
| | 531-536 | 533 | 29 | 31 | 280 | 19.5% | 89 | |
| | 536-540 | 538 | 28 | 30 | 280 | 19.7% | 161 | |
| 45.0-47.0 | 540-545 | 542 | 37 | 40 | 340 | 21.9% | 412 | 418 |
| | 545-550 | 547 | 36 | 39 | 320 | 18.9% | 210 | |
| | 550-555 | 552 | 35 | 38 | 140 | 20.9% | 42 | |
| | 555-560 | 557 | 34 | 37 | 80 | 20.6% | 2 | |
| | 560-564 | 562 | 33 | 36 | 100 | 22.7% | 3 | |
| 47.0-49.0 | 564-570 | 567 | 41 | 45 | 180 | 24.3% | 259 | |
| | 570-576 | 573 | 40 | 43 | 120 | 21.6% | 4 | |
| R | 570-576 | 573 | 40 | 44 | 120 | 22.3% | 4 | |
| | 576-582 | 579 | 39 | 42 | 60 | 21.3% | 0 | |
| | 582-588 | 585 | 38 | 41 | 80 | 22.3% | 0 | |

Plattsburgh Solid Core Data-June5-7, 1996
Separate Phase Analysis-12AW

| Barrel Depth (ft) | Sample Depth (in) | Sample Depth (in) | Sample Depth (m) | Jar Number | Vial Number | TLV (ppm) | Moisture Content (%) | HC conc (mg sep. ph./ kg dry soil) | Rep HC Conc (mg/kg) |
|-------------------------|-------------------------|-------------------------|------------------------|---------------|----------------|--------------|----------------------------|--|---------------------------|
| 35.0-36.5 | 420-424 | 422 | 10.7 | 182 | 84 | 40 | 5.4% | 0 | |
| | 424-431 | 428 | 10.9 | 181 | 83 | 40 | 2.0% | 0 | |
| | 431-438 | 434 | 11.0 | 180 | 82 | 50 | 1.9% | 0 | |
| 36.5-38.0 | 438-444 | 441 | 11.2 | 184 | 86 | 60 | 3.1% | 0 | |
| | 444-450 | 447 | 11.4 | 183 | 85 | 80 | 16.1% | 0 | |
| | 456-464 | 460 | 11.7 | 186 | 88 | 200 | 15.9% | 0 | |
| 38.0-39.5 R | 456-464 | 460 | 11.7 | 186 | 89 | 200 | 15.4% | 0 | |
| | 464-472 | 468 | 11.9 | 185 | 87 | 500 | 20.6% | 402 | |
| | 474-476 | 475 | 12.1 | 187 | 90 | 2800 | 17.0% | 4528 | 4852 |
| 39.5-41.0 | 476-478 | 477 | 12.1 | 48 | 52 | 480 | 16.9% | 200 | |
| | 478-480 | 479 | 12.2 | 47 | 51 | 380 | 16.8% | 58 | |
| | 481-483 | 482 | 12.2 | 46 | 50 | 1000 | 17.0% | 2104 | 1994 |
| | 483-485 | 484 | 12.3 | 45 | 49 | 1100 | 15.7% | 4616 | |
| | 485-487 | 486 | 12.3 | 44 | 48 | 2000 | 17.1% | 15615 | |
| | 488-490 | 489 | 12.4 | 43 | 47 | 2400 | 18.3% | 7268 | |
| 41.0-42.5 | 490-492 | 491 | 12.5 | 42 | 46 | 2000 | 18.5% | 4435 | |
| | 492-495 | 493 | 12.5 | 53 | 58 | 680 | 25.0% | 6021 | |
| | 495-498 | 496 | 12.6 | 52 | 57 | 760 | 22.5% | 1438 | |
| | 498-501 | 499 | 12.7 | 51 | 56 | 560 | 21.4% | 853 | |
| | 501-504 | 502 | 12.8 | 50 | 54 | 660 | 21.6% | 706 | |
| | 501-504 | 502 | 12.8 | 50 | 55 | 660 | 20.9% | 1141 | |
| 42.5-44.5 R | 504-507 | 505 | 12.8 | 49 | 53 | 2000 | 20.5% | 11667 | |
| | 510-516 | 513 | 13.0 | 56 | 61 | 100 | 20.4% | 0 | |
| | 518-524 | 521 | 13.2 | 55 | 60 | 100 | 19.3% | 0 | |
| 44.5-46.5 | 526-532 | 529 | 13.4 | 54 | 59 | 100 | 21.1% | 0 | 0 |
| | 534-540 | 537 | 13.6 | 60 | 65 | 80 | 18.5% | 0 | |
| | 534-540 | 537 | 13.6 | 60 | 66 | 80 | 19.5% | 0 | |
| R | 540-546 | 543 | 13.8 | 59 | 64 | 100 | 19.8% | 0 | |
| | 546-551 | 549 | 13.9 | 58 | 63 | 60 | 19.2% | 0 | |
| | 551-556 | 554 | 14.1 | 57 | 62 | 80 | 19.9% | 0 | |
| 46.5-48.5 | 558-566 | 562 | 14.3 | 63 | 69 | 50 | 18.4% | 0 | |
| | 566-574 | 570 | 14.5 | 62 | 68 | 60 | 19.7% | 0 | |
| | 574-580 | 578 | 14.7 | 61 | 67 | 40 | 19.3% | 0 | |

Plattsburgh Solid Core Data-June5-7, 1996
Separate Phase Analysis-12AX

| Barrel Depth (ft) | Sample Depth (in) | Sample Depth (in) | Sample Depth (m) | Jar Number | Vial Number | TLV (ppm) | Moisture Content (%) | HC conc (mg sep. ph./ kg dry soil) | Rep HC Conc (mg/kg) |
|-------------------------|-------------------------|-------------------------|------------------------|---------------|----------------|--------------|----------------------------|--|---------------------------|
| 5.0-6.5 | 60-66 | 63 | 1.6 | 190 | 93 | 0 | 4.3% | 0 | 0 |
| | 66-72 | 69 | 1.8 | 189 | 92 | 0 | 3.9% | 0 | 0 |
| | 72-78 | 75 | 1.9 | 188 | 91 | 0 | 7.3% | 0 | 0 |
| 6.5-8.0 | 78-84 | 81 | 2.1 | 193 | 96 | 20 | 4.9% | 0 | 0 |
| | 84-90 | 87 | 2.2 | 192 | 95 | 20 | 3.5% | 0 | 0 |
| | 90-96 | 93 | 2.4 | 191 | 94 | 0 | 4.4% | 0 | 0 |
| 8.0-9.5 | 108-114 | 111 | 2.8 | 194 | 97 | 20 | 7.7% | 0 | 0 |
| 9.5-11.0 | 126-132 | 129 | 3.3 | 195 | 98 | 20 | 4.5% | 0 | 0 |
| 11.0-12.5 | 144-150 | 147 | 3.7 | 196 | 99 | 20 | 5.9% | 0 | 0 |
| 12.5-14.0 | 162-168 | 165 | 4.2 | 197 | 100 | 40 | 6.1% | 0 | 0 |
| | 162-168 | 165 | 4.2 | 197 | 101 | 40 | 6.2% | 0 | 0 |
| 14.0-15.5 | 180-186 | 183 | 4.6 | 198 | 102 | 20 | 8.0% | 0 | 0 |
| 15.5-17.0 | 198-204 | 201 | 5.1 | 199 | 103 | 40 | 5.3% | 0 | 0 |
| 17.0-18.5 | 216-222 | 219 | 5.6 | 200 | 104 | 0 | 10.8% | 0 | 0 |
| 18.5-20.0 | 234-240 | 237 | 6.0 | 201 | 105 | 40 | 10.5% | 0 | 0 |
| 20.0-21.5 | 252-258 | 255 | 6.5 | 202 | 106 | 20 | 5.0% | 0 | 0 |
| 21.5-23.0 | 270-276 | 273 | 6.9 | 203 | 107 | 60 | 10.1% | 0 | 0 |
| 23.0-24.5 | 288-294 | 291 | 7.4 | 204 | 108 | 60 | 5.7% | 0 | 0 |
| 24.5-26.0 | 306-312 | 309 | 7.8 | 205 | 109 | 50 | 6.9% | 0 | 0 |
| 26.0-27.5 | 324-330 | 327 | 8.3 | 206 | 110 | 60 | 5.7% | 0 | 0 |
| 27.5-29.0 | 342-348 | 345 | 8.8 | 207 | 111 | 60 | 15.1% | 0 | 0 |
| 29.0-30.5 | 360-366 | 363 | 9.2 | 208 | 112 | 60 | 11.0% | 0 | 0 |
| | 360-366 | 363 | 9.2 | 208 | 113 | 60 | 11.4% | 0 | 0 |
| 30.5-32.0 | 378-384 | 381 | 9.7 | 209 | 114 | 80 | 22.0% | 0 | 0 |
| 32.0-33.5 | 396-402 | 399 | 10.1 | 210 | 115 | 90 | 22.9% | 0 | 0 |
| 33.5-35.0 | 414-420 | 417 | 10.6 | 211 | 116 | 80 | 24.6% | 1 | 1 |
| 35.0-36.5 | 432-438 | 435 | 11.0 | 212 | 117 | 100 | 25.5% | 2 | 2 |

Plattsburgh Solid Core Data-June5-7, 1996
Separate Phase Analysis-12AY

| Barrel Depth (ft) | Sample Depth (in) | Sample Depth (in) | Sample Depth (m) | Jar Number | Vial Number | TLV (ppm) | Moisture Content (%) | HC conc (mg sep. ph./ kg dry soil) | Rep HC Conc (mg/kg) |
|-------------------------|-------------------------|-------------------------|------------------------|---------------|----------------|--------------|----------------------------|--|---------------------------|
| 36.0-37.5 | 432-438 | 435 | 11.0 | 215 | 132 | 40 | 4.5% | 0 | |
| | 438-444 | 441 | 11.2 | 214 | 131 | 40 | 7.0% | 0 | |
| | 444-450 | 447 | 11.4 | 213 | 130 | 40 | 17.6% | 0 | 0 |
| 37.5-39.0 | 450-456 | 453 | 11.5 | 218 | 135 | 200 | 16.7% | 0 | |
| | 456-462 | 459 | 11.7 | 217 | 134 | 760 | 16.0% | 2 | |
| | 462-468 | 465 | 11.8 | 216 | 133 | 2600 | 23.7% | 3237 | |
| 39.0-41.0 | 468-473 | 470 | 11.9 | 68 | 122 | 380 | 20.6% | 1106 | |
| | 473-478 | 475 | 12.1 | 67 | 121 | 1200 | 19.8% | 733 | |
| | 478-483 | 480 | 12.2 | 66 | 120 | 2800 | 19.8% | 5013 | 5527 |
| | 483-488 | 485 | 12.3 | 65 | 119 | 3600 | 17.9% | 18152 | |
| | 488-492 | 490 | 12.4 | 64 | 118 | 3600 | 19.0% | 9316 | |
| | 492-499 | 495 | 12.6 | 71 | 125 | 160 | 20.6% | 0 | |
| 41.0-43.0 | 499-506 | 502 | 12.8 | 70 | 124 | 60 | 21.7% | 0 | |
| | 506-513 | 509 | 12.9 | 69 | 123 | 60 | 21.5% | 0 | |
| | 516-523 | 519 | 13.2 | 74 | 129 | 280 | 19.7% | 51 | |
| 43.0-45.0 | 523-530 | 526 | 13.4 | 73 | 127 | 140 | 20.4% | 8 | |
| | 523-530 | 526 | 13.4 | 73 | 128 | 140 | 21.1% | 4 | |
| | 530-537 | 533 | 13.5 | 72 | 126 | 140 | 21.5% | 2 | |

Plattsburgh Solid Core Data-June5-7, 1996

Separate Phase Analysis-12AZ

| Barrel | Sample Depth (ft) | Sample Depth (in) | Sample Depth (m) | Jar Number | Vial Number | TLV (ppm) | Moisture Content (%) | HC conc (mg sep. ph./ kg dry soil) | Rep HC Conc (mg/kg) |
|-----------|-------------------|-------------------|------------------|------------|-------------|-----------|----------------------|------------------------------------|---------------------|
| 35.0-36.5 | 420-422 | 421 | 10.7 | 221 | 174 | 0 | 4.7% | 7 | 7 |
| | 422-430 | 426 | 10.8 | 220 | 173 | 0 | 6.1% | 12 | 12 |
| | 430-438 | 434 | 11.0 | 219 | 172 | 0 | 2.9% | 0 | 0 |
| | 438-444 | 441 | 11.2 | 224 | 177 | 20 | 8.1% | 0 | 0 |
| 36.5-38.0 | 444-450 | 447 | 11.4 | 223 | 176 | 20 | 12.1% | 0 | 0 |
| | 450-456 | 453 | 11.5 | 222 | 175 | 100 | 16.5% | 0 | 0 |
| | 456-462 | 459 | 11.7 | 227 | 181 | 1600 | 16.4% | 2087 | 2087 |
| | 462-468 | 465 | 11.8 | 226 | 179 | 1800 | 14.9% | 299 | 299 |
| R | 462-468 | 465 | 11.8 | 226 | 180 | 1800 | 14.8% | 403 | 393 |
| | 468-472 | 471 | 12.0 | 225 | 178 | 3800 | 18.0% | 4613 | 4613 |
| | 472-474 | 473 | 12.0 | 84 | 147 | 2200 | 15.9% | 4305 | 4305 |
| | 474-476 | 475 | 12.1 | 83 | 145 | 2800 | 14.9% | 12853 | 12853 |
| R | 474-476 | 475 | 12.1 | 83 | 146 | 2800 | 14.9% | 8342 | 8342 |
| | 476-478 | 477 | 12.1 | 82 | 144 | 2400 | 16.7% | 8801 | 8801 |
| | 478-480 | 479 | 12.2 | 81 | 143 | 4400 | 17.6% | 12382 | 12382 |
| | 480-482 | 481 | 12.2 | 80 | 142 | 1400 | 18.6% | 3114 | 3114 |
| 41.0-43.0 | 482-484 | 483 | 12.3 | 79 | 141 | 1600 | 20.1% | 3693 | 3693 |
| | 484-486 | 485 | 12.3 | 78 | 139 | 1400 | 22.9% | 3061 | 3061 |
| | 486-488 | 487 | 12.4 | 77 | 138 | 1800 | 23.1% | 7687 | 7687 |
| | 488-490 | 489 | 12.4 | 76 | 137 | 3000 | 22.7% | 10362 | 10362 |
| 41.0-43.0 | 490-492 | 491 | 12.5 | 75 | 136 | 2800 | 23.0% | 9403 | 9403 |
| | 492-498 | 495 | 12.6 | 88 | 151 | 3800 | 19.2% | 10136 | 10136 |
| | 498-504 | 501 | 12.7 | 87 | 150 | 2600 | 19.2% | 902 | 919 |
| | 504-510 | 507 | 12.9 | 86 | 149 | 400 | 20.9% | 35 | 35 |
| 43.0-45.0 | 510-516 | 513 | 13.0 | 85 | 148 | 200 | 21.2% | 54 | 54 |
| | 516-522 | 519 | 13.2 | 92 | 155 | 2000 | 19.3% | 1506 | 1506 |
| | 522-528 | 525 | 13.3 | 91 | 154 | 360 | 20.7% | 78 | 78 |
| | 528-534 | 531 | 13.5 | 90 | 153 | 280 | 20.4% | 13 | 13 |
| 45.0-47.0 | 534-540 | 537 | 13.6 | 89 | 152 | 280 | 21.0% | 12 | 12 |
| | 540-550 | 545 | 13.8 | 94 | 157 | 480 | 18.8% | 23 | 23 |
| | 540-550 | 545 | 13.8 | 94 | 158 | 480 | 19.7% | 5 | 5 |
| | 552-562 | 557 | 14.1 | 93 | 156 | 200 | 21.4% | 1 | 1 |
| 47.0-49.0 | 564-570 | 567 | 14.4 | 99 | 162 | 1400 | 18.4% | 230 | 230 |
| | 570-576 | 573 | 14.6 | 98 | 161 | 100 | 19.9% | 1 | 1 |
| | 576-582 | 579 | 14.7 | 97 | 160 | 100 | 19.5% | 0 | 0 |
| | 582-588 | 585 | 14.9 | 95 | 159 | 140 | 20.0% | 0 | 0 |
| 49.0-51.0 | 588-594 | 591 | 15.0 | 103 | 166 | 220 | 21.3% | 0 | 0 |
| | 594-600 | 597 | 15.2 | 102 | 165 | 80 | 21.0% | 0 | 0 |
| | 600-606 | 603 | 15.3 | 101 | 164 | 100 | 20.8% | 0 | 0 |
| | 606-612 | 609 | 15.5 | 100 | 163 | 160 | 21.6% | 0 | 0 |
| 51.0-53.0 | 612-617 | 615 | 15.6 | 108 | 171 | 80 | 21.1% | 0 | 0 |
| | 617-622 | 619 | 15.7 | 107 | 140 | 40 | 21.3% | 2 | 0 |
| | 622-627 | 624 | 15.8 | 106 | 170 | 40 | 23.0% | 0 | 0 |
| | 627-632 | 629 | 16.0 | 105 | 168 | 60 | 22.5% | 1 | 1 |
| R | 627-632 | 629 | 16.0 | 105 | 169 | 60 | 22.6% | 0 | 0 |
| | 632-636 | 634 | 16.1 | 104 | 167 | 60 | 25.2% | 0 | 0 |

Plattsburgh Solid Core Data-June 5-7, 1996

Separate Phase Analysis-12BA

| Barrel Depth (ft) | Sample Depth (in) | Sample Depth (m) | Jar Number | Vial Number | TLV (ppm) | Moisture Content (%) | HC conc (mg sep. ph./ kg dry soil) | Rep HC Conc (mg/kg) |
|-------------------------|-------------------------|------------------------|---------------|----------------|--------------|----------------------------|--|---------------------------|
| 35.0-36.5 | 420-428 | 424 | 229 | 210 | 40 | 9.9% | 0 | 0 |
| | 428-436 | 432 | 228 | 209 | 0 | 3.3% | 0 | |
| 36.5-38.0 | 438-446 | 442 | 231 | 212 | 0 | 13.4% | 0 | |
| | 446-454 | 450 | 230 | 211 | 80 | 19.1% | 37 | 36 |
| 38.0-39.5 | 456-464 | 460 | 233 | 213 | 3400 | 14.7% | 5920 | |
| | 464-472 | 468 | 232 | 214 | 4400 | 22.9% | 14908 | |
| 39.5-41.0 | 474-479 | 476 | 236 | 218 | 2800 | 18.7% | 5080 | |
| | 479-484 | 481 | 235 | 216 | 4700 | 16.5% | 5818 | |
| R | 479-484 | 481 | 235 | 217 | 4700 | 16.7% | 6848 | |
| | 484-489 | 486 | 234 | 215 | 4200 | 22.5% | 12134 | |
| 41.0-43.0 | 492-499 | 495 | 111 | 184 | 2000 | 19.8% | 13713 | |
| | 499-506 | 502 | 110 | 183 | 2400 | 18.9% | 5128 | |
| | 506-513 | 509 | 109 | 182 | 560 | 20.8% | 605 | |
| 43.0-45.0 | 516-523 | 519 | 115 | 188 | 1600 | 21.0% | 2944 | |
| | 523-530 | 527 | 114 | 187 | 1800 | 21.5% | 662 | |
| | 530-537 | 533 | 113 | 186 | 580 | 23.0% | 236 | |
| 45.0-47.0 | 540-547 | 543 | 117 | 190 | 120 | 20.8% | 15 | 16 |
| | 547-554 | 550 | 116 | 189 | 80 | 21.2% | 2172 *Field Spike | |
| | 554-561 | 557 | 112 | 185 | 140 | 21.0% | 0 | |
| 47.0-49.0 | 564-570 | 567 | 121 | 195 | 220 | 19.6% | 11 | |
| | 570-576 | 573 | 120 | 194 | 60 | 20.4% | 0 | |
| | 576-582 | 579 | 119 | 193 | 40 | 18.4% | 0 | |
| | 582-588 | 585 | 118 | 191 | 60 | 19.2% | 8905 *Field Spike | |
| R | 582-588 | 585 | 118 | 192 | 60 | 19.3% | 0 | |
| 49.0-51.0 | 588-594 | 591 | 125 | 201 | 200 | 19.7% | 63 | |
| | 594-600 | 597 | 124 | 198 | 660 | 18.1% | 73 | 74 |
| | 600-606 | 603 | 123 | 197 | 30 | 19.1% | 2 | |
| | 606-612 | 609 | 122 | 196 | 40 | 20.2% | 0 | |
| 51.0-53.0 | 612-616 | 615 | 131 | 208 | 30 | 19.9% | 6 | |
| | 616-620 | 618 | 130 | 207 | 80 | 19.5% | 2 | |
| | 620-624 | 622 | 129 | 206 | 20 | 21.1% | 0 | |
| | 624-628 | 626 | 128 | 204 | 20 | 22.4% | 0 | |
| R | 624-628 | 626 | 128 | 205 | 20 | 22.9% | 0 | |
| | 628-632 | 630 | 127 | 203 | 20 | 20.6% | 0 | |
| | 632-636 | 634 | 126 | 202 | 40 | 25.2% | 0 | |

Separate Phase

| Plattsburgh Solid Soil Core Data - August 19-23, 1996 | | | | | | | | | | | | | |
|---|---------------------|-------|--------------------|------|--------------------|------|-----------|---------|----------------------|-----------|------------|----------------------|---------------------------|
| Separate Phase Analysis-12BB | | | | | | | | | | | | | |
| Borehole | Depth Below Surface | | Avg Depth | | Below Surface | | Avg Depth | | Below Surface | | Avg Depth | | Phase in Dry Soil (mg/kg) |
| ID | Surface (in) | (in) | Below Surface (in) | (in) | Below Surface (ft) | (ft) | TLV (ppm) | Jar ID | Moisture Content (%) | Sample ID | Area Units | Replicate Area Units | Mass of Wet Soil (kg) |
| 12BB | 408-417 | 412.5 | 34.38 | 80 | 2 | 6.1 | 202 | 0 | 0.01446 | 0 | 0 | 0.01446 | 0 |
| 12BB | 417-426 | 421.5 | 35.13 | 0 | 1 | 2.2 | 201 | 0 | 0.01302 | 0 | 0 | 0.01302 | 0 |
| 12BB | 426-432 | 429 | 35.75 | 0 | 5 | 2.0 | 205 | 0 | 0.01423 | 0 | 0 | 0.01423 | 0 |
| 12BB | 432-438 | 435 | 36.25 | 0 | 4 | 2.4 | 204 | 0 | 0.01524 | 0 | 0 | 0.01524 | 0 |
| 12BB | 438-444 | 441 | 36.75 | 0 | 3 | 4.5 | 203 | 0 | 0.01334 | 0 | 0 | 0.01334 | 0 |
| 12BB | 444-450 | 447 | 37.25 | 50 | 8 | 16.3 | 208 | 24398 | 0.01566 | 185 | 0 | 0.01566 | 185 |
| 12BB | 450-456 | 453 | 37.75 | 40 | 7 | 18.4 | 207 | 137931 | 0.01603 | 1039 | 0 | 0.01603 | 1039 |
| 12BB | 456-462 | 459 | 38.25 | 0 | 6 | 18.0 | 206 | 88376 | 0.01827 | 582 | 0 | 0.01827 | 582 |
| 12BB | 464-466 | 465 | 38.75 | 280 | 10 | 15.9 | 215 | 53042 | 0.01828 | 343 | 0 | 0.01828 | 343 |
| 12BB | 466-468 | 467 | 38.92 | 100 | 136 | 15.9 | 214 | 49595 | 0.01854 | 316 | 0 | 0.01854 | 316 |
| 12BB | 468-470 | 469 | 39.08 | 160 | 135 | 16.6 | 213 | 124296 | 0.01738 | 850 | 0 | 0.01738 | 850 |
| 12BB | 470-472 | 471 | 39.25 | 480 | 134 | 17.2 | 212 | 68100 | 0.01634 | 498 | 0 | 0.01634 | 498 |
| 12BB | 472-474 | 473 | 39.42 | 1200 | 133 | 17.8 | 312 | 768026 | 0.01713 | 5388 | 0 | 0.01713 | 5388 |
| 12BB | 472-474 | 473 | 39.42 | 1200 | 133 | 17.8 | 211 | 246200 | 0.01576 | 1877 | 0 | 0.01576 | 1877 |
| 12BB | 477-480 | 478.5 | 39.88 | 4300 | 9 | 19.4 | 209 | 2312252 | 0.01743 | 16164 | 0 | 0.01743 | 16164 |
| 12BB | 480-486 | 483 | 40.25 | 160 | 139 | 18.8 | 218 | 0 | 0.01724 | 0 | 0 | 0.01724 | 0 |
| 12BB | 480-488 | 484 | 40.33 | 860 | 142 | 17.6 | 313 | 134087 | 0.01764 | 912 | 0 | 0.01764 | 912 |
| 12BB | 480-488 | 484 | 40.33 | 860 | 142 | 17.6 | 221 | 98801 | 0.01772 | 669 | 0 | 0.01772 | 669 |
| 12BB | 488-496 | 492 | 41.00 | 1000 | 141 | 18.2 | 220 | 110133 | 0.01641 | 809 | 0 | 0.01641 | 809 |
| 12BB | 492-498 | 495 | 41.25 | 720 | 137 | 20.9 | 217 | 67750 | 0.0151 | 553 | 0 | 0.0151 | 553 |
| 12BB | 496-504 | 500 | 41.67 | 1000 | 140 | 18.0 | 219 | 433915 | 0.01741 | 3000 | 0 | 0.01741 | 3000 |
| 12BB | 504-516 | 510 | 42.50 | 200 | 144 | 18.7 | 223 | 2531 | 0.01812 | 17 | 0 | 0.01812 | 17 |
| 12BB | 504-516 | 510 | 42.50 | 200 | 144 | 18.7 | 224 | 2398 | 0.01781 | 16 | 0 | 0.01781 | 16 |
| 12BB | 516-528 | 522 | 43.50 | 260 | 143 | 19.3 | 222 | 3191 | 0.01876 | 21 | 0 | 0.01876 | 21 |
| 12BB | 528-536 | 532 | 44.33 | 210 | 147 | 15.4 | 227 | 0 | 0.01701 | 0 | 0 | 0.01701 | 0 |
| 12BB | 536-544 | 540 | 45.00 | 80 | 146 | 16.8 | 226 | 0 | 0.01569 | 0 | 0 | 0.01569 | 0 |
| 12BB | 544-552 | 548 | 45.67 | 100 | 145 | 17.9 | 225 | 0 | 0.01703 | 0 | 0 | 0.01703 | 0 |
| 12BB | 552-564 | 558 | 46.50 | 80 | 150 | 17.6 | 314 | 0 | 0.01805 | 0 | 0 | 0.01805 | 0 |
| 12BB | 552-564 | 558 | 46.50 | 80 | 150 | 17.6 | 230 | 0 | 0.01678 | 0 | 0 | 0.01678 | 0 |
| 12BB | 564-576 | 570 | 47.50 | 80 | 148 | 18.5 | 228 | 0 | 0.01825 | 0 | 0 | 0.01825 | 0 |

Separate Phase

| Plattsburgh Solid Soil Core Data - August 19-23, 1996 | | | | | | | | | | | | | |
|---|-------------|-------|---------------|-----------|---------------|------|-----|----------|--------|-------|-----------|---------|----------|
| Separate Phase Analysis-12BF | | | | | | | | | | | | | |
| Borehole | Depth Below | | Avg Depth | Avg Depth | | TLV | Jar | Moisture | Sample | Area | Replicate | Mass of | Phase in |
| | Surface | (in) | Below Surface | (ft) | Below Surface | | | | | | | | |
| ID | (in) | | | | (ppm) | ID | (%) | ID | Units | Units | Units | (kg) | (mg/kg) |
| 12BF | 420-426 | 423 | 35.25 | 0 | 13 | 2.1 | 233 | 0 | | | | 0.01405 | 0 |
| 12BF | 426-432 | 429 | 35.75 | 0 | 12 | 1.6 | 232 | 0 | | | | 0.01371 | 0 |
| 12BF | 432-438 | 435 | 36.25 | 0 | 11 | 1.5 | 231 | 0 | | | | 0.01445 | 0 |
| 12BF | 438-444 | 441 | 36.75 | 0 | 16 | 11.9 | 236 | 0 | | | | 0.01459 | 0 |
| 12BF | 444-450 | 447 | 37.25 | 0 | 15 | 16.1 | 235 | 0 | | | | 0.01631 | 0 |
| 12BF | 450-456 | 453 | 37.75 | 0 | 14 | 16.1 | 234 | 0 | | | | 0.01625 | 0 |
| 12BF | 456-459 | 457.5 | 38.13 | 100 | 158 | 36.5 | 244 | 0 | | | | 0.00964 | 0 |
| 12BF | 459-462 | 460.5 | 38.38 | 100 | 157 | 28.0 | 243 | 0 | | | | 0.0159 | 0 |
| 12BF | 462-464 | 463 | 38.58 | 60 | 156 | 19.4 | 242 | 0 | | | | 0.01397 | 0 |
| 12BF | 464-466 | 465 | 38.75 | 80 | 155 | 14.8 | 241 | 0 | | | | 0.01481 | 0 |
| 12BF | 466-468 | 467 | 38.92 | 110 | 154 | 15.9 | 315 | 0 | | | | 0.01731 | 0 |
| 12BF | 466-468 | 467 | 38.92 | 110 | 154 | 15.9 | 240 | 0 | 0 | | | 0.01708 | 0 |
| 12BF | 468-470 | 469 | 39.08 | 440 | 153 | 17.5 | 239 | 68624 | | | | 0.01538 | 535 |
| 12BF | 470-472 | 471 | 39.25 | 850 | 152 | 17.5 | 238 | 439909 | | | | 0.01775 | 2970 |
| 12BF | 472-474 | 473 | 39.42 | 1200 | 151 | 18.7 | 237 | 548563 | | | | 0.01759 | 3778 |
| 12BF | 474-480 | 477 | 39.75 | 580 | 161 | 24.6 | 247 | 310930 | | | | 0.01763 | 2241 |
| 12BF | 474-480 | 477 | 39.75 | 1000 | 165 | 16.2 | 301 | 209700 | | | | 0.01739 | 1429 |
| 12BF | 480-486 | 483 | 40.25 | 860 | 164 | 15.6 | 316 | 280984 | | | | 0.01761 | 1882 |
| 12BF | 480-486 | 483 | 40.25 | 1000 | 160 | 17.6 | 246 | 754450 | | | | 0.01523 | 5944 |
| 12BF | 480-486 | 483 | 40.25 | 860 | 164 | 15.6 | 250 | 284523 | 150370 | | | 0.01633 | 2054 |
| 12BF | 486-492 | 489 | 40.75 | 1000 | 159 | 14.6 | 245 | 648088 | | | | 0.01751 | 4328 |
| 12BF | 486-492 | 489 | 40.75 | 3000 | 163 | 15.1 | 249 | 1172797 | | | | 0.01671 | 8242 |
| 12BF | 492-498 | 495 | 41.25 | 2800 | 162 | 10.3 | 248 | 1878938 | | | | 0.01753 | 12061 |
| 12BF | 498-506 | 502 | 41.83 | 1000 | 170 | 17.7 | 304 | 804157 | | | | 0.01751 | 5516 |
| 12BF | 506-514 | 510 | 42.50 | 5000 | 169 | 15.8 | 303 | 2868427 | | | | 0.0176 | 19253 |
| 12BF | 514-522 | 518 | 43.17 | 1200 | 166 | 16.7 | 302 | 225395 | | | | 0.01824 | 1471 |
| 12BF | 522-528 | 525 | 43.75 | 480 | 172 | 16.5 | 308 | 65503 | | | | 0.01758 | 443 |
| 12BF | 528-534 | 531 | 44.25 | 120 | 171 | 15.4 | 307 | 3182 | | | | 0.01698 | 22 |
| 12BF | 534-540 | 537 | 44.75 | 120 | 168 | 18.9 | 306 | 0 | | | | 0.01689 | 0 |
| 12BF | 540-546 | 543 | 45.25 | 180 | 167 | 17.3 | 305 | 0 | | | | 0.01715 | 0 |

Separate Phase

| | | | | | | | | | | | |
|------|---------|-----|-------|----|-----|------|-----|---|---|---------|---|
| 12BF | 546-554 | 550 | 45.83 | 80 | 175 | 19.9 | 311 | 0 | | 0.01687 | 0 |
| 12BF | 554-562 | 558 | 46.50 | 60 | 174 | 16.3 | 310 | 0 | 0 | 0.01624 | 0 |
| 12BF | 562-570 | 566 | 47.17 | 80 | 173 | 19.3 | 309 | 0 | | 0.01569 | 0 |

[illegible]

[illegible]

APPENDIX V COMPUTER PROGRAM LISTINGS

```

1 OPEN "datf" FOR OUTPUT AS #1
2 DIM we(12), ve(12), wf(12), vf(12), vs(12), ws(12), canal(100), delta(100)
3 DIM cj(100), ck(100), kk(100, 100), ast(100, 100), b(100), bst(100), func(15)
4 DIM d(100), bvec(100), abl(100), fk(100, 100), wai(100), vai(100), coz(15)
5 PRINT #1, "Advection, Diffusion and Transience"
6 PRINT #1, "Finite Element-Finite Difference Solution"
7 PRINT #1, "Constant Concentration on Capillary Fringe"
8 PRINT #1, "Ostendorf et al. 1997 Uniform Grid"
9 PRINT #1,
10 REM Read in and Display Arrays
11 READ goo, ree
12 READ nn, zf, re, q, dref, cam, det, theta, lam, coo, tmax, tave, omeg, phase,
13 nnn = (nn + 2) ^ .5
14 PRINT "nodes="; nn; "zf="; zf; "re="; re; "q="; q; "det="; det; "dref="; dref
15 PRINT "cam="; cam; "theta="; theta; "lam="; lam; "coo="; coo; "tmax="; tmax;
17 PRINT "goo="; goo; "ree="; ree
20 lamp = lam + 1 / det
27 dz = zf / (nnn + 1)
29 dr = re / nnn
35 REM Initialize Terms and compute flow vector
37 GOSUB 1300
41 REM Solve and Print the Time Steps
43 GOSUB 1500
95 END
98 DATA .00,15,47,13,15,1e-10,4.37e-6,.001,30.25e5,.288,5e-7
99 DATA 0,12,282,1.99e-7,0,1.74e-6
1000 REM Subroutine to find cj(n)
1005 FOR i10 = 1 TO n - 1
1008 m = n - i10
1010 ab = kk(1, 1)
1011 bb = b(1)
1012 FOR j10 = 2 TO m + 1
1014 abl(j10) = kk(1, j10)
1016 NEXT j10
1018 FOR k10 = 1 TO m
1020 FOR l10 = 1 TO m
1025 kk(k10, l10) = kk(k10 + 1, l10 + 1) - kk(k10 + 1, 1) * abl(l10 + 1) / ab
1030 NEXT l10
1035 b(k10) = b(k10 + 1) - kk(k10 + 1, 1) * bb / ab
1040 NEXT k10, i10
1050 cj(n) = b(1) / kk(1, 1)
1052 RETURN
1100 REM Gauss Elimination nn by nn Array
1105 FOR i11 = 1 TO nn
1110 n = nn - i11 + 1
1115 ns = n
1118 REM Store the n by n Array
1120 GOSUB 1200
1125 GOSUB 1000
1140 REM Reset the n-1 by n-1 Array with c(n) Known
1145 FOR j11 = 1 TO n - 1
1150 b(j11) = bst(j11) - ast(j11, n) * cj(n)
1152 FOR k11 = 1 TO n - 1
1154 kk(j11, k11) = ast(j11, k11)
1156 NEXT k11, j11, i11
1170 RETURN
1200 REM Store the Array Subroutine
1205 FOR i12 = 1 TO ns
1210 bst(i12) = b(i12)
1220 FOR j12 = 1 TO ns

```

```

225 ast(i12, j12) = kk(i12, j12)
1230 NEXT j12, i12
240 RETURN
300 REM Initialize, compute the flow vectors and radial boundary concentration
1301 REM Compute the interior flow vector
1302 REM find the radius and elevation
1303 bstar = EXP(zf * SQR(lam / dref)) - EXP(-zf * SQR(lam / dref))
1304 k13 = 0
1305 zref = dz
1306 func(1) = cam * (EXP((zf - zref) * SQR(lam / dref)) - EXP(-(zf - zref) * SQ
1307 rref = dr
1308 FOR i13 = 1 TO nnn - 2
1309 rref = rref + dr
1310 k13 = k13 + 1
1311 coz(i13) = cam
1312 vai(k13) = q * rref / (2 * 3.14 * (rref ^ 2 + zref ^ 2) ^ 1.5)
1313 wai(k13) = q * zref / (2 * 3.14 * (rref ^ 2 + zref ^ 2) ^ 1.5)
1323 canal(k13) = goo * (1 - EXP(q / (2 * 3.14 * theta * dref) * (1 / ree - 1 /
1325 NEXT i13
1326 FOR j13 = 2 TO nnn
1328 rref = -dr
1329 zref = zref + dz
1331 func(j13) = cam * (EXP((zf - zref) * SQR(lam / dref)) - EXP(-(zf - zref) *
1332 FOR l13 = 1 TO nnn
1333 k13 = k13 + 1
1334 rref = rref + dr
1336 vai(k13) = q * rref / (2 * 3.14 * (rref ^ 2 + zref ^ 2) ^ 1.5)
1337 wai(k13) = q * zref / (2 * 3.14 * (rref ^ 2 + zref ^ 2) ^ 1.5)
1339 canal(k13) = goo * (1 - EXP(q / (2 * 3.14 * theta * dref) * (1 / ree - 1 /
1340 NEXT l13, j13
1341 REM Boundary Vector Velocities
1342 FOR m13 = 1 TO nnn + 1
1343 we(m13) = q * dz * m13 / (2 * 3.14 * (re ^ 2 + (dz * m13) ^ 2) ^ 1.5)
1345 ve(m13) = q * re / (2 * 3.14 * (re ^ 2 + (dz * m13) ^ 2) ^ 1.5)
1347 ws(m13) = q * zf / (2 * 3.14 * ((dr * (m13 - 1)) ^ 2 + zf ^ 2) ^ 1.5)
1348 vs(m13) = q * (m13 - 1) * dr / (2 * 3.14 * ((dr * (m13 - 1)) ^ 2 + zf ^ 2)
1350 IF m > 3 GOTO 1360
1351 wf(1) = q / (2 * 3.14 * dz ^ 2)
1352 vf(1) = 0
1353 wf(2) = q * dz / (2 * 3.14 * (dr ^ 2 + dz ^ 2) ^ 1.5)
1354 vf(2) = q * dr / (2 * 3.14 * (dr ^ 2 + dz ^ 2) ^ 1.5)
1355 vf(3) = q / (2 * 3.14 * dr ^ 2)
1358 wf(3) = 0
1359 GOTO 1375
1360 vf(m13) = q / (2 * 3.14 * ((m13 - 2) * dr) ^ 2)
1361 wf(m13) = 0
1375 NEXT m13
1380 wfe = 0
1382 vfe = q / (2 * 3.14 * re ^ 2)
1384 wse = q * zf / (2 * 3.14 * (re ^ 2 + zf ^ 2))
1386 vse = q * re / (2 * 3.14 * (re ^ 2 + zf ^ 2))
1387 REM initialize ck
1389 FOR n13 = 1 TO nn
1390 ck(n13) = 0!
1392 NEXT n13
1394 ff = 4 * dr * dz / (9 * det)
1395 RETURN
1400 REM Initialize the Arrays
1401 FOR j14 = 1 TO nn
1402 FOR k14 = 1 TO nn

```

```

1403 di = (d(j14) + d(k14)) / 2
1404 vi = (vai(k14) + vai(j14)) / 2
1405 wi = (wai(k14) + wai(j14)) / 2
1406 REM Compute the k generics
1407 GOSUB 1700
1409 IF j14 = k14 GOTO 1448
1410 IF (j14 - k14) = 1 GOTO 1444
1411 IF (j14 - k14) = -1 GOTO 1441
1412 IF (j14 - k14) = nnn GOTO 1438
1413 IF (j14 - k14) = -nnn GOTO 1435
1414 IF (j14 - k14) = (nnn + 1) GOTO 1430
1415 IF (j14 - k14) = -(nnn + 1) GOTO 1427
1416 IF (j14 - k14) = (nnn - 1) GOTO 1424
1417 IF (j14 - k14) = -(nnn - 1) GOTO 1421
1418 kk(j14, k14) = 0
1419 fk(j14, k14) = 0
1420 GOTO 1451
1421 kk(j14, k14) = kul
1422 fk(j14, k14) = ff / 16
1423 GOTO 1451
1424 kk(j14, k14) = kdr
1425 fk(j14, k14) = ff / 16
1426 GOTO 1451
1427 kk(j14, k14) = kur
1428 fk(j14, k14) = ff / 16
1429 GOTO 1451
1430 kk(j14, k14) = kdl
1431 fk(j14, k14) = ff / 16
1434 GOTO 1451
1435 kk(j14, k14) = kvu
1436 fk(j14, k14) = ff / 4
1437 GOTO 1451
1438 kk(j14, k14) = kvd
1439 fk(j14, k14) = ff / 4
1440 GOTO 1451
1441 kk(j14, k14) = krr
1442 fk(j14, k14) = ff / 4
1443 GOTO 1451
1444 kk(j14, k14) = krl
1445 fk(j14, k14) = ff / 4
1446 GOTO 1451
1448 kk(j14, k14) = kf
1449 fk(j14, k14) = ff
1451 NEXT k14, j14
1453 REM Zero the Row Elements and Adjust the No Flux KII
1454 FOR l14 = 1 TO nnn
1455 vi = vai(l14 * nnn - 1)
1456 wi = wai(l14 * nnn - 1)
1457 di = d(l14 * nnn - 1)
1458 GOSUB 1700
1459 kk(l14 * nnn - 1, l14 * nnn - 1) = kfo
1460 fk(l14 * nnn - 1, l14 * nnn - 1) = ff / 2
1461 vi = (vai(l14 * nnn - 1) + vai((l14 + 1) * nnn - 1)) / 2
1462 wi = (wai(l14 * nnn - 1) + wai((l14 + 1) * nnn - 1)) / 2
1463 di = (d(l14 * nnn - 1) + d((l14 + 1) * nnn - 1)) / 2
1464 GOSUB 1700
1468 kk(l14 * nnn - 1, (l14 + 1) * nnn - 1) = kvuo
1469 fk(l14 * nnn - 1, (l14 + 1) * nnn - 1) = ff / 8
1476 kk((l14 + 1) * nnn - 1, l14 * nnn - 1) = kvdo
1481 fk((l14 + 1) * nnn - 1, l14 * nnn - 1) = ff / 8

```

```

1 OPEN "datf" FOR OUTPUT AS #1
2 DIM canal(90), delta(90), rr(100), zz(100), alg(6), rig(6)
3 DIM cj(100), ck(100), kk(90, 90), ast(90, 90), b(100), bst(100), func(15)
4 DIM d(102), bvec(100), ab1(100), fk(90, 90), wai(90), vai(90)
5 PRINT #1, "Advection, Diffusion and Transience"
6 PRINT #1, "Finite Element-Finite Difference Solution with 6 Point Gauss Quadra
7 PRINT #1, "No Flux on Capillary Fringe"
8 PRINT #1, "Ostendorf et al. 1997 Uniform Grid"
9 PRINT #1, "Advection and Diffusion Test"
10 REM Read in and Display Arrays
11 READ ginf
12 READ nn, zf, re, q, dref, cam, theta, lam, tmax, tave, omeg, phase, dt
13 FOR im = 1 TO 6
14 READ alg(im), rig(im)
16 NEXT im
23 nnn = nn ^ .5
24 PRINT #1, "nodes="; nn; "zf="; zf; "re="; re; "q="; q; "dref="; dref; "omeg="
25 PRINT #1, "cam="; cam; "theta="; theta; "lam="; lam; "tmax="; tmax; "tave=";
27 PRINT #1, "ginf="; ginf
29 dz = zf / (nnn - 1)
30 dr = re / (nnn - 1)
31 det = 605000!
32 lamp = lam + 1 / det
34 REM Initialize Arrays
35 GOSUB 1300
37 PRINT #1, "dz="; dz; "dr="; dr; "det="; det
38 REM Solve and Print the Time Steps
39 GOSUB 1500
95 END
98 DATA .01,49,13,15,1.00e-4,2.33e-5,0.0,.288,5e-12
99 DATA 12,282,1.99e-7,0,1.74e-6
100 DATA .46791,.23862,.46791,-.23862,.36076,.66120,.36076,-.66120
101 DATA .17132,.93246,.17132,-.93246
1000 REM Subroutine to find cj(n)
1001 FOR i10 = 1 TO n - 1
1002 m = n - i10
1004 ab = kk(1, 1)
1005 BB = b(1)
1012 FOR j10 = 2 TO m + 1
1014 ab1(j10) = kk(1, j10)
1016 NEXT j10
1018 FOR k10 = 1 TO m
1020 FOR l10 = 1 TO m
1021 IF ab = 0 GOTO 1028
1025 kk(k10, l10) = kk(k10 + 1, l10 + 1) - kk(k10 + 1, 1) * ab1(l10 + 1) / ab
1026 GOTO 1030
1028 kk(k10, l10) = kk(k10 + 1, l10 + 1)
1030 NEXT l10
1031 IF ab = 0 GOTO 1038
1035 b(k10) = b(k10 + 1) - kk(k10 + 1, 1) * BB / ab
1036 GOTO 1040
1038 b(k10) = b(k10 + 1)
1040 NEXT k10, i10
1044 IF kk(1, 1) = 0 GOTO 1052
1046 cj(n) = b(1) / kk(1, 1)
1047 delta(n) = (cj(n) - canal(n)) / canal(n)
1051 PRINT n; cj(n); canal(n); delta(n)
1052 PRINT #1, n; cj(n); canal(n); delta(n)
1053 RETURN
1100 REM Gauss Elimination nn by nn Array

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1105 FOR I11 = 1 TO nn - nnn - 1
1110 n = nn - nnn - 1 - I11 + 1
1115 ns = n
1118 REM Store the n by n Array
1120 GOSUB 1200
1125 GOSUB 1000
1140 REM Reset the n-1 by n-1 Array with c(n) Known
1145 FOR j11 = 1 TO n - 1
1150 b(j11) = bst(j11) - ast(j11, n) * cj(n)
1152 FOR k11 = 1 TO n - 1
1154 kk(j11, k11) = ast(j11, k11)
1156 NEXT k11, j11, I11
1170 RETURN
1200 REM Store the Array Subroutine
1205 FOR i12 = 1 TO ns
1210 bst(i12) = b(i12)
1220 FOR j12 = 1 TO ns
1225 ast(i12, j12) = kk(i12, j12)
1230 NEXT j12, i12
1240 RETURN
1300 REM Initialize, compute the flow vectors and radial boundary concentration
1302 REM find the radius and elevation
1303 bstar = EXP(zf * SQR(lam / dref)) - EXP(-zf * SQR(lam / dref))
1304 k13 = 0
1305 zref = -dz
1306 FOR i13 = 1 TO nnn
1307 zref = zref + dz
1308 func(i13) = cam * (EXP((zf - zref) * SQR(lam / dref)) - EXP(-(zf - zref) *
1317 rref = -dr
1318 FOR j13 = 1 TO nnn
1320 rref = rref + dr
1321 k13 = k13 + 1
1322 rr(k13) = rref
1323 zz(k13) = zref
1326 IF k13 = 1 GOTO 1329
1328 canal(k13) = ginf * (1 - EXP(-q / (2 * 3.14 * theta * dref * SQR(rref ^ 2 +
1329 NEXT j13, i13
1387 REM initialize ck
1389 FOR l13 = 1 TO nn
1390 ck(l13) = 0!
1392 NEXT l13
1394 ff = 4 * theta * dr * dz / (9 * det)
1395 RETURN
1400 REM Initialize the Interior Arrays
1401 FOR i14 = 1 TO nn
1402 FOR j14 = 1 TO nn
1404 REM Zero the Boundary Elements
1405 vi = (vai(i14) + vai(j14)) / 2
1406 wi = (wai(i14) + wai(j14)) / 2
1407 di = (d(i14) + d(j14)) / 2
1408 GOSUB 3000
1409 IF kk(i14, j14) = 0 GOTO 1485
1410 GOSUB 1700
1413 IF i14 = j14 GOTO 1480
1415 IF (i14 - j14) = 1 GOTO 1474
1417 IF (i14 - j14) = -1 GOTO 1461
1418 IF (i14 - j14) = nnn GOTO 1455
1419 IF (i14 - j14) = -nnn GOTO 1450
1420 IF (i14 - j14) = (nnn + 1) GOTO 1445
1421 IF (i14 - j14) = -(nnn + 1) GOTO 1440

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1721 kdl = theta * di * (-dz / dr - dr / dz) / 6 - vi * dz / 12 - wi * dr / 12 +
1722 kul = theta * di * (-dz / dr - dr / dz) / 6 - vi * dz / 12 + wi * dr / 12 +
1723 kdr = theta * di * (-dz / dr - dr / dz) / 6 + vi * dz / 12 - wi * dr / 12 +
1730 RETURN
1800 REM Load the Bottom Vector and Corners
1801 go1 = func(1)
1802 go2 = func(1)
1803 go3 = cam
1804 wi = (wai(1) + wf(3)) / 2
1805 vi = (vai(1) + vf(3)) / 2
1806 di = d(1)
1807 GOSUB 1700
1808 bvec(1) = go3 * (ff / 16 - kdl)
1809 wi = (wai(1) + wf(2)) / 2
1810 vi = (vai(1) + vf(2)) / 2
1811 GOSUB 1700
1812 bvec(1) = bvec(1) + go2 * (ff / 4 - krl)
1813 wi = (wai(1) + wf(4)) / 2
1814 vi = (vai(1) + vf(4)) / 2
1815 GOSUB 1700
1816 bvec(1) = bvec(1) + cam * (ff / 4 - kvd)
1817 wi = (wai(1) + wf(5)) / 2
1818 vi = (vai(1) + vf(5)) / 2
1819 GOSUB 1700
1820 bvec(1) = bvec(1) + cam * (ff / 16 - kdr)
1821 wi = (wai(nnn - 1) + wf(1)) / 2
1822 vi = (vai(nnn - 1) + vf(1)) / 2
1823 di = d(nnn - 1)
1824 GOSUB 1700
1825 bvec(nnn - 1) = go1 * (ff / 8 - kvdo)
1826 wi = (wai(nnn - 1) + wf(2)) / 2
1827 vi = (vai(nnn - 1) + vf(2)) / 2
1828 GOSUB 1700
1830 bvec(nnn - 1) = bvec(nnn - 1) + go2 * (ff / 16 - kdr)
1832 wi = (wai(nnn) + wf(1)) / 2
1834 vi = (vai(nnn) + vf(1)) / 2
1836 di = d(nnn)
1838 GOSUB 1700
1840 bvec(nnn) = go1 * (ff / 16 - kdl)
1842 wi = (wai(nnn) + wf(2)) / 2
1844 vi = (vai(nnn) + vf(2)) / 2
1848 GOSUB 1700
1850 bvec(nnn) = bvec(nnn) + go2 * (ff / 4 - kvd)
1852 wi = (wai(nnn + 1) + wf(2)) / 2
1854 vi = (vai(nnn + 1) + vf(2)) / 2
1855 di = d(nnn + 1)
1858 GOSUB 1700
1860 bvec(nnn + 1) = go2 * (ff / 16 - kdl)
1861 FOR i18 = 2 TO nnn - 3
1862 wi = (wai(i18) + wf(i18 + 2)) / 2
1863 vi = (vai(i18) + vf(i18 + 2)) / 2
1864 di = d(i18)
1865 GOSUB 1700
1866 bvec(i18) = bvec(i18) + cam * (ff / 16 - kdl)
1867 wi = (wai(i18) + wf(i18 + 3)) / 2
1868 vi = (vai(i18) + vf(i18 + 3)) / 2
1869 GOSUB 1700
1870 bvec(i18) = bvec(i18) + cam * (ff / 4 - kvd)
1871 wi = (wai(i18) + wf(i18 + 4)) / 2
1872 vi = (vai(i18) + vf(i18 + 4)) / 2

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1874 GOSUB 1700
1875 bvec(i18) = bvec(i18) + cam * (ff / 16 - kdr)
1878 NEXT i18
1885 RETURN
1900 REM Diffusivity vector
1902 k19 = 0
1908 zref = 0
1910 FOR i19 = 1 TO nnn
1911 zref = zref + dz
1912 rref = -dr
1913 FOR j19 = 1 TO nnn
1915 k19 = k19 + 1
1917 rref = rref + dr
1925 temp = tave + tmax * EXP((zref - zf) * SQR(omeg / (2 * dt))) * SIN(omeg *
1930 d(k19) = dref * (temp / tave) ^ 1.75
1935 NEXT j19, i19
1940 RETURN
```

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1482 kk(l14 * nnn - 2, l14 * nnn - 1) = 0
1483 fk(l14 * nnn - 2, l14 * nnn - 1) = 0
1485 kk(l14 * nnn - 1, l14 * nnn - 2) = 0
1486 fk(l14 * nnn - 1, l14 * nnn - 2) = 0
1488 kk(l14 * nnn - 2, (l14 + 1) * nnn - 1) = 0
1489 fk(l14 * nnn - 2, (l14 + 1) * nnn - 1) = 0
1491 kk((l14 + 1) * nnn - 1, l14 * nnn - 2) = 0
1492 fk((l14 + 1) * nnn - 1, l14 * nnn - 2) = 0
1493 kk(l14 * nnn - 1, (l14 + 1) * nnn - 2) = 0
1494 fk(l14 * nnn - 1, (l14 + 1) * nnn - 2) = 0
1495 kk((l14 + 1) * nnn - 2, l14 * nnn - 1) = 0
1496 fk((l14 + 1) * nnn - 1, l14 * nnn - 1) = 0
1498 NEXT l14
1499 RETURN
1500 REM Solve the Time Step
1501 t = 0
1502 REM Time Step
1503 FOR i15 = 1 TO 10
1504 t = t + det
1505 REM Compute the diffusivity vector for the time step
1507 GOSUB 1900
1516 REM Compute the KK array
1517 GOSUB 1400
1518 REM Load the bvec vectors
1519 GOSUB 1600
1520 REM run the time step and display
1532 GOSUB 1100
1533 PRINT #1, "time="; t
1534 PRINT "time="; t
1535 FOR l15 = 1 TO nn
1537 ck(l15) = cj(l15)
1565 NEXT l15
1567 PRINT #1, cj(1); cj(1 + nnn); cj(1 + 2 * nnn); cj(1 + 3 * nnn); cj(1 + 4 *
1585 NEXT i15
1587 RETURN
1600 REM Set the B and bvec Vectors for the time step
1601 FOR i16 = 1 TO nn
1602 bvec(i16) = 0
1604 NEXT i16
1606 REM Load the Bottom Vector and Corners
1607 GOSUB 1800
1608 REM load the radial concentration vector
1609 FOR j16 = 2 TO nnn - 1
1610 REM Outside Vector
1612 wi = (wai(j16 * nnn - 2) + we(j16)) / 2
1615 vi = (vai(j16 * nnn - 2) + ve(j16)) / 2
1616 di = d(j16 * nnn - 2)
1617 GOSUB 1700
1618 bvec(j16 * nnn - 2) = func(j16) * (ff / 4 - krr)
1619 wi = (wai(j16 * nnn - 2) + we(j16 - 1)) / 2
1620 vi = (vai(j16 * nnn - 2) + ve(j16 - 1)) / 2
1621 GOSUB 1700
1626 bvec(j16 * nnn - 2) = bvec(j16 * nnn - 2) + func(j16 - 1) * (ff / 16 - kdl)
1628 wi = (wai(j16 * nnn - 2) + we(j16 + 1)) / 2
1630 vi = (vai(j16 * nnn - 2) + ve(j16 + 1)) / 2
1632 GOSUB 1700
1634 bvec(j16 * nnn - 2) = bvec(j16 * nnn - 2) + func(j16 + 1) * (ff / 16 - kul)
1635 NEXT j16
1636 REM Lower Corner
1637 wi = (wai(nnn - 2) + wf(nnn)) / 2

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1638 vi = (vai(nnn - 2) + vf(nnn)) / 2
1639 di = d(nnn - 2)
1640 GOSUB 1700
1641 bvec(nnn - 2) = cam * (ff / 16 - kdl)
1643 wi = (wai(nnn - 2) + wf(nnn + 1)) / 2
1644 vi = (vai(nnn - 2) + vf(nnn + 1)) / 2
1645 GOSUB 1700
1646 bvec(nnn - 2) = bvec(nnn - 2) + cam * (ff / 4 - kvd)
1647 wi = (wai(nnn - 2) + wfe) / 2
1648 vi = (vai(nnn - 2) + vfe) / 2
1650 GOSUB 1700
1652 bvec(nnn - 2) = bvec(nnn - 2) + cam * (ff / 16 - kdr)
1654 wi = (wai(nnn - 2) + we(1)) / 2
1655 vi = (vai(nnn - 2) + ve(1)) / 2
1657 GOSUB 1700
1658 bvec(nnn - 2) = bvec(nnn - 2) + func(1) * (ff / 4 - krr)
1660 wi = (wai(nnn - 2) + we(2)) / 2
1661 vi = (vai(nnn - 2) + ve(2)) / 2
1662 GOSUB 1700
1663 bvec(nnn - 2) = bvec(nnn - 2) + func(2) * (ff / 16 - kur)
1664 REM Upper Corner
1665 wi = (wai(nn) + ws(nnn - 1)) / 2
1666 vi = (vai(nn) + vs(nnn - 1)) / 2
1667 di = d(nn)
1668 GOSUB 1700
1669 bvec(nn) = coo * (ff / 16 - kul)
1670 wi = (wai(nn) + ws(nnn)) / 2
1671 vi = (vai(nn) + vs(nnn)) / 2
1672 GOSUB 1700
1673 bvec(nn) = bvec(nn) + coo * (ff / 4 - kvu)
1674 wi = (wai(nn) + wse) / 2
1675 vi = (vai(nn) + vse) / 2
1676 GOSUB 1700
1677 bvec(nn) = bvec(nn) + coo * (ff / 16 - kur)
1678 wi = (wai(nn) + we(nnn)) / 2
1679 vi = (vai(nn) + ve(nnn)) / 2
1680 GOSUB 1700
1681 bvec(nn) = bvec(nn) + func(nnn) * (ff / 4 - krr)
1683 wi = (wai(nn) + we(nnn - 1)) / 2
1684 vi = (vai(nn) + ve(nnn - 1)) / 2
1686 GOSUB 1700
1688 bvec(nn) = bvec(nn) + func(nnn - 1) * (ff / 16 - kdr)
1692 REM set the bvector
1693 FOR l16 = 1 TO nn
1694 b(l16) = bvec(l16)
1695 FOR m16 = 1 TO nn
1696 b(l16) = b(l16) + ck(m16) * fk(l16, m16)
1697 NEXT m16
1698 NEXT l16
1699 RETURN
1700 REM k generic
1742 kf = 4 * theta * di * (dz / dr + dr / dz) / 3 + 4 * lamp * dr * dz / 9
1713 kfo = 2 * theta * di * (dz / dr + dr / dz) / 3 + vi * dz / 3 + 2 * lamp *
1714 krl = theta * di * (-2 * dz / dr + dr / dz) / 3 - vi * dz / 3 + lamp * dr
1715 krr = theta * di * (-2 * dz / dr + dr / dz) / 3 + vi * dz / 3 + lamp * dr
1716 kvd = theta * di * (dz / dr - 2 * dr / dz) / 3 - wi * dr / 3 + lamp * dr
1717 kvu = theta * di * (dz / dr - 2 * dr / dz) / 3 + wi * dr / 3 + lamp * dr
1718 kvdo = theta * di * (dz / dr - 2 * dr / dz) / 6 + vi * dz / 12 - wi * dr /
1719 kvuo = theta * di * (dz / dr - 2 * dr / dz) / 6 + vi * dz / 12 + wi * dr /
1720 kur = theta * di * (-dz / dr - dr / dz) / 6 + vi * dz / 12 + wi * dr / 12

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1422 IF (i14 - j14) = (nnn - 1) GOTO 1435
1423 IF (i14 - j14) = -(nnn - 1) GOTO 1430
1424 kk(i14, j14) = 0
1425 xx = 0
1426 fk(i14, j14) = 0
1427 yy = 0
1428 GOTO 1485
1430 GOSUB 3700
1434 GOTO 1485
1435 GOSUB 4700
1438 GOTO 1485
1440 GOSUB 4600
1444 GOTO 1485
1445 GOSUB 3500
1448 GOTO 1485
1450 GOSUB 3400
1453 GOTO 1485
1455 GOSUB 3300
1460 GOTO 1485
1461 GOSUB 3600
1465 GOTO 1485
1474 GOSUB 3200
1478 GOTO 1485
1480 GOSUB 3100
1485 NEXT j14, i14
1498 RETURN
1500 REM Solve the Time Step
1501 t = 0
1506 FOR j15 = 1 TO nn
1508 FOR k15 = 1 TO nn
1510 kk(j15, k15) = 1
1512 NEXT k15, j15
1517 REM Compute the diffusivity vector for the time step
1518 GOSUB 1900
1519 REM Compute the KK array
1520 GOSUB 1400
1521 FOR i15 = 1 TO 30
1522 t = t + det
1523 PRINT #1, "time="; t
1524 REM Load the bvecs
1525 GOSUB 1600
1526 PRINT "time="; t
1528 REM run the time step and display
1532 GOSUB 1100
1535 FOR l15 = 1 TO nn
1537 ck(l15) = cj(l15)
1565 NEXT l15
1566 PRINT "time="; t
1585 NEXT i15
1587 RETURN
1600 REM Set the B and bvec Vectors for the time step
1601 FOR i16 = 1 TO nn
1602 bvec(i16) = 0
1604 NEXT i16
1605 REM Load the Bottom Inside Corner, and Surface Vectors
1606 GOSUB 2000
1607 GOSUB 1800
1608 REM load the radial vector and Outside Corner
1609 REM Outside Interiors
1611 FOR j16 = 2 TO nnn - 2

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1612 k16 = j16 * nnn - 1
1613 bvec(k16) = canal(k16 - nnn + 1) * (fk(k16, k16 - nnn + 1) - kk(k16, k16 -
1619 bvec(k16) = bvec(k16) + canal(k16 + 1) * (fk(k16, k16 + 1) - kk(k16, k16 +
1628 bvec(k16) = bvec(k16) + canal(k16 + nnn + 1) * (fk(k16, k16 + nnn + 1) - k
1635 NEXT j16
1636 REM Lower Outside Corner
1637 bvec(nnn - 1) = canal(nnn) * (fk(nnn - 1, nnn) - kk(nnn - 1, nnn)) + canal
1650 REM Load the b
1652 FOR l16 = 1 TO nn
1654 b(l16) = bvec(l16)
1655 FOR m16 = 1 TO nn
1657 b(l16) = b(l16) + ck(m16) * fk(l16, m16)
1660 NEXT m16, l16
1699 RETURN
1700 REM k generic
1712 kf = 4 * theta * di * (dz / dr + dr / dz) / 3 + 4 * theta * lamp * dr * dz
1713 kfo = 2 * theta * di * (dz / dr + dr / dz) / 3 + vi * dz / 3 + 2 * theta *
1714 krl = theta * di * (-2 * dz / dr + dr / dz) / 3 - vi * dz / 3 + theta * lam
1715 krr = theta * di * (-2 * dz / dr + dr / dz) / 3 + vi * dz / 3 + theta * lam
1716 kvd = theta * di * (dz / dr - 2 * dr / dz) / 3 - wi * dr / 3 + theta * lam
1717 kvu = theta * di * (dz / dr - 2 * dr / dz) / 3 + wi * dr / 3 + theta * lam
1718 kvdo = theta * di * (dz / dr - 2 * dr / dz) / 6 + vi * dz / 12 - wi * dr /
1719 kvuo = theta * di * (dz / dr - 2 * dr / dz) / 6 + vi * dz / 12 + wi * dr /
1720 kur = theta * di * (-dz / dr - dr / dz) / 6 + vi * dz / 12 + wi * dr / 12
1721 kdl = theta * di * (-dz / dr - dr / dz) / 6 - vi * dz / 12 - wi * dr / 12 +
1722 kul = theta * di * (-dz / dr - dr / dz) / 6 - vi * dz / 12 + wi * dr / 12 +
1723 kdr = theta * di * (-dz / dr - dr / dz) / 6 + vi * dz / 12 - wi * dr / 12
1724 kfod = 2 * theta * di * (dz / dr + dr / dz) / 3 - wi * dz / 3 + 2 * theta
1726 krro = theta * di * (-2 * dz / dr + dr / dz) / 6 + vi * dz / 6 + wi * dr /
1728 krlo = theta * di * (-2 * dz / dr + dr / dz) / 6 - vi * dz / 6 + wi * dr /
1730 RETURN
1800 REM Load the Bottom Inside Corner
1805 bvec(2) = ginf * (fk(2, 1) - kk(2, 1))
1809 bvec(nnn + 1) = ginf * (fk(nnn + 1, 1) - kk(nnn + 1, 1))
1814 bvec(nnn + 2) = ginf * (fk(nnn + 2, 1) - kk(nnn + 2, 1))
1885 RETURN
1900 REM Diffusivity vector
1902 k19 = 0
1908 zref = -dz
1910 FOR i19 = 1 TO nnn
1911 zref = zref + dz
1912 rref = -dr
1913 FOR j19 = 1 TO nnn
1915 k19 = k19 + 1
1917 rref = rref + dr
1925 temp = tave + tmax * EXP((zref - zf) * SQR(omeg / (2 * dt))) * SIN(omeg * t
1930 d(k19) = dref * (temp / tave) ^ 1.75
1935 NEXT j19, i19
1940 RETURN
2000 REM Surface Boundary Vector
2002 REM Upper Surface
2004 FOR i20 = 2 TO nnn - 2
2005 j20 = nnn * (nnn - 2) + i20
2009 bvec(j20) = canal(j20 + nnn - 1) * (fk(j20, j20 + nnn - 1) - kk(j20, j20 +
2012 bvec(j20) = bvec(j20) + canal(j20 + nnn) * (fk(j20, j20 + nnn) - kk(j20, j
2016 bvec(j20) = bvec(j20) + canal(j20 + nnn + 1) * (fk(j20, j20 + nnn + 1) - kk
2017 NEXT i20
2018 REM Upper Outside Corner
2032 k20 = nn - nnn - 1
2034 bvec(k20) = canal(k20 + nnn - 1) * (fk(k20, k20 + nnn - 1) - kk(k20, k20 +

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2042 bvec(k20) = bvec(k20) + canal(k20 + nnn) * (fk(k20, k20 + nnn) - kk(k20, k2
2052 bvec(k20) = bvec(k20) + canal(k20 + nnn + 1) * (fk(k20, k20 + nnn + 1) - kk
2055 bvec(k20) = bvec(k20) + canal(k20 + 1) * (fk(k20, k20 + 1) - kk(k20, k20 +
2060 bvec(k20) = bvec(k20) + canal(k20 - nnn + 1) * (fk(k20, k20 - nnn + 1) - kk
2070 REM Upper Inside Corner
2072 l20 = nn - 2 * nnn + 1
2074 bvec(l20) = canal(l20 + nnn) * (fk(l20, l20 + nnn) - kk(l20, l20 + nnn)) +
2092 RETURN
2700 REM k generic by 6 point Gauss Quadrature
2701 kaaaa = 0
2702 faaaa = 0
2703 kbaba = 0
2704 fbaba = 0
2705 kbbbb = 0
2706 fbbbb = 0
2707 kabab = 0
2708 fabab = 0
2709 kaaba = 0
2710 faaba = 0
2711 kabbb = 0
2712 fabbb = 0
2713 kbaaa = 0
2714 fbaaa = 0
2715 kbbab = 0
2716 fbbab = 0
2717 kaaab = 0
2718 faaab = 0
2719 kbabb = 0
2720 fbabb = 0
2721 kabaa = 0
2722 fabaa = 0
2723 kbbba = 0
2724 fbbba = 0
2725 kaabb = 0
2726 faabb = 0
2727 kbaab = 0
2728 fbaab = 0
2729 kbbaa = 0
2730 fbbaa = 0
2731 kabba = 0
2732 fabba = 0
2733 rb = ra + dr
2734 zb = za + dz
2735 FOR i27 = 1 TO 6
2736 rri = (ra + rb) / 2 + dr * rig(i27) / 2
2737 wri = dr * alg(i27) / 2
2741 zkaaaa = 0
2742 zfaaaa = 0
2743 zkbaba = 0
2744 zfbaba = 0
2745 zkbbbb = 0
2746 zfbbbb = 0
2747 zkabab = 0
2748 zfabab = 0
2749 zkaaba = 0
2750 zfaaba = 0
2751 zkabbb = 0
2752 zfabbb = 0
2753 zkbaaa = 0
2754 zfbaaa = 0

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2755 zkbabb = 0
2756 zfbabb = 0
2757 zkaaab = 0
2758 zfaaab = 0
2759 zkbabb = 0
2760 zfbabb = 0
2761 zkabaa = 0
2762 zfabaa = 0
2763 zkbbba = 0
2764 zfbbaa = 0
2765 zkaabb = 0
2766 zfaabb = 0
2767 zkbaab = 0
2768 zfbaab = 0
2769 zkbbaa = 0
2770 zfbbaa = 0
2771 zkabba = 0
2772 zfabba = 0
2776 FOR j27 = 1 TO 6
2777 zzi = (za + zb) / 2 + dz * rig(j27) / 2
2778 wzi = dz * alg(j27) / 2
2779 vvi = q * rri / (2 * 3.14 * (rri ^ 2 + zzi ^ 2) ^ 1.5)
2780 wwi = q * zzi / (2 * 3.14 * (rri ^ 2 + zzi ^ 2) ^ 1.5)
2781 GOSUB 2900
2801 zkaaaa = zkaaaa + wzi * fkaaaa
2802 zfaaaa = zfaaaa + wzi * ffaaaa
2803 zkbaba = zkbaba + wzi * fkbaba
2804 zfbaba = zfbaba + wzi * ffbaba
2805 zkbbbb = zkbbbb + wzi * fkbbbb
2806 zfbbbb = zfbbbb + wzi * ffbbbb
2807 zkabab = zkabab + wzi * fkabab
2808 zfabab = zfabab + wzi * ffabab
2809 zkaaba = zkaaba + wzi * fkaaba
2810 zfaaba = zfaaba + wzi * ffaaba
2811 zkabbb = zkabbb + wzi * fkabbb
2812 zfabbb = zfabbb + wzi * ffabbb
2813 zkbaaa = zkbaaa + wzi * fkbaaa
2814 zfbaaa = zfbaaa + wzi * ffbaaa
2815 zkbabb = zkbabb + wzi * fkbabb
2816 zfbabb = zfbabb + wzi * ffbabb
2817 zkaaab = zkaaab + wzi * fkaaab
2818 zfaaab = zfaaab + wzi * ffaaab
2819 zkbabb = zkbabb + wzi * fkbabb
2820 zfbabb = zfbabb + wzi * ffbabb
2821 zkabaa = zkabaa + wzi * fkabaa
2822 zfabaa = zfabaa + wzi * ffabaa
2823 zkbbba = zkbbba + wzi * fkbbaa
2824 zfbbaa = zfbbaa + wzi * ffbbaa
2825 zkaabb = zkaabb + wzi * fkaabb
2826 zfaabb = zfaabb + wzi * ffaabb
2827 zkbaab = zkbaab + wzi * fkbaab
2828 zfbaab = zfbaab + wzi * ffbaab
2829 zkbbaa = zkbbaa + wzi * fkbbaa
2830 zfbbaa = zfbbaa + wzi * ffbbaa
2831 zkabba = zkabba + wzi * fkabba
2832 zfabba = zfabba + wzi * ffabba
2850 NEXT j27
2851 kaaaa = kaaaa + wri * zkaaaa
2852 faaaa = faaaa + wri * zfaaaa
2853 kbaba = kbaba + wri * zkbaba

```

```

2854 fbaba = fbaba + wri * zfbaba
2855 kbbbbb = kbbbbb + wri * zkbbbbb
2856 fbbbbb = fbbbbb + wri * zfbbbb
2857 kabab = kabab + wri * zkabab
2858 fabab = fabab + wri * zfabab
2859 kaaba = kaaba + wri * zkaaba
2860 faaba = faaba + wri * zfaaba
2861 kabbb = kabbb + wri * zkabbb
2862 fabbb = fabbb + wri * zfabbb
2863 kbaaa = kbaaa + wri * zkbaaa
2864 fbaaa = fbaaa + wri * zfbaaa
2865 kbbab = kbbab + wri * zkbbab
2866 fbbab = fbbab + wri * zfbbab
2867 kaaab = kaaab + wri * zkaaab
2868 faaab = faaab + wri * zfaaab
2869 kbabb = kbabb + wri * zkbabb
2870 fbabb = fbabb + wri * zfbabb
2871 kabaa = kabaa + wri * zkabaa
2872 fabaa = fabaa + wri * zfabaa
2873 kbbba = kbbba + wri * zkbbba
2874 fbbba = fbbba + wri * zfbbaa
2875 kaabb = kaabb + wri * zkaabb
2876 faabb = faabb + wri * zfaabb
2877 kbaab = kbaab + wri * zkbaab
2878 fbaab = fbaab + wri * zfbaab
2879 kbbaa = kbbaa + wri * zkbbaa
2880 fbbaa = fbbaa + wri * zfbbaa
2881 kabba = kabba + wri * zkabba
2882 fabba = fabba + wri * zfabba

```

```

2897 NEXT i27

```

```

2899 RETURN

```

```

2900 REM Individual Arguments

```

```

2911 fkaaaa = rri * (theta * di * ((zzi - zb) ^ 2 + (rri - rb) ^ 2) + vvi * (rb
2912 ffaaaa = rri * theta * ((rb - rri) * (zb - zzi)) ^ 2 / (det * (dz * dr) ^ 2
2913 fkbaba = rri * (theta * di * ((zb - zzi) ^ 2 + (ra - rri) ^ 2) - vvi * (rri
2914 ffbaba = rri * theta * ((ra - rri) * (zb - zzi)) ^ 2 / (det * (dr * dz) ^ 2
2915 fkbbbb = rri * (theta * di * ((zzi - za) ^ 2 + (rri - ra) ^ 2) - vvi * (rri
2916 ffbbbb = rri * theta * ((ra - rri) * (za - zzi)) ^ 2 / (det * (dr * dz) ^ 2
2917 fkabab = rri * (theta * di * ((za - zzi) ^ 2 + (rb - rri) ^ 2) + vvi * (rb
2918 ffabab = rri * theta * ((rb - rri) * (za - zzi)) ^ 2 / (det * (dr * dz) ^ 2
2919 fkaaba = rri * (theta * di * (-(zzi - zb) ^ 2 + (rri - rb) * (ra - rri)) +
2920 ffaaba = rri * theta * (rb - rri) * (zb - zzi) ^ 2 * (rri - ra) / (det * (d
2921 fkabbb = rri * (theta * di * (-(zzi - za) ^ 2 + (rb - rri) * (rri - ra)) +
2922 ffabbb = rri * theta * (rb - rri) * (zzi - za) ^ 2 * (rri - ra) / (det * (d
2923 fkbaaa = rri * (theta * di * (-(zzi - zb) ^ 2 + (rri - rb) * (ra - rri)) -
2924 ffbaaa = rri * theta * (rb - rri) * (zb - zzi) ^ 2 * (rri - ra) / (det * (d
2925 fkbbab = rri * (theta * di * (-(za - zzi) ^ 2 + (rb - rri) * (rri - ra)) -
2926 ffbbab = rri * theta * (rb - rri) * (zzi - za) ^ 2 * (rri - ra) / (det * (d
2927 fkaaab = rri * (theta * di * ((zzi - zb) * (za - zzi) - (rri - rb) ^ 2) - v
2928 ffaaab = rri * theta * (rb - rri) ^ 2 * (zb - zzi) * (zzi - za) / (det * (d
2929 fkbabb = rri * (theta * di * ((zb - zzi) * (zzi - za) - (ra - rri) ^ 2) - v
2930 ffbabb = rri * theta * (rri - ra) ^ 2 * (zb - zzi) * (zzi - za) / (det * (d
2931 fkabaa = rri * (theta * di * ((zzi - zb) * (za - zzi) - (rri - rb) ^ 2) - v
2932 ffabaa = rri * theta * (rb - rri) ^ 2 * (zb - zzi) * (zzi - za) / (det * (d
2933 fkbbaa = rri * (theta * di * ((zb - zzi) * (zzi - za) - (ra - rri) ^ 2) - v
2934 ffbbaa = rri * theta * (rri - ra) ^ 2 * (zb - zzi) * (zzi - za) / (det * (d
2935 fkaabb = rri * (theta * di * ((zzi - zb) * (zzi - za) + (rri - rb) * (rri -
2936 ffaabb = rri * theta * (rb - rri) * (zb - zzi) * (rri - ra) * (zzi - za) /
2937 fkbaab = rri * (theta * di * ((zb - zzi) * (za - zzi) + (ra - rri) * (rb -
2938 ffbaab = rri * theta * (rb - rri) * (zb - zzi) * (rri - ra) * (zzi - za) /

```



```

2939 fkbbaa = rri * (theta * di * ((zzi - zb) * (zzi - za) + (rri - rb) * (rri
2940 ffbbaa = rri * theta * (rb - rri) * (zb - zzi) * (rri - ra) * (zzi - za) /
2941 fkabba = rri * (theta * di * ((zb - zzi) * (za - zzi) + (ra - rri) * (rb -
2942 ffabba = rri * theta * (rb - rri) * (zb - zzi) * (zzi - za) * (rri - ra) /
2950 RETURN
3000 REM Zero the Surface
3001 IF i14 > (nn - nnn) GOTO 3025
3002 REM Zero the Outside
3003 FOR i30 = 1 TO nnn
3005 IF i14 = (i30 * nnn) GOTO 3025
3007 NEXT i30
3010 REM Zero the Lower Corner
3014 IF i14 = 1 GOTO 3025
3020 GOTO 3035
3025 kk(i14, j14) = 0
3026 xx = 0
3027 fk(i14, j14) = 0
3028 yy = 0
3035 RETURN
3100 REM Kf and kfos
3104 IF i14 < nnn GOTO 3130
3105 REM kfo
3107 FOR i31 = 1 TO nnn - 2
3108 IF i14 = (nnn * i31 + 1) GOTO 3111
3110 GOTO 3126
3111 REM Interior Full
3112 ra = rr(i14)
3114 za = zz(i14)
3115 GOSUB 2700
3116 kkk = kaaaa
3117 fff = faaaa
3118 za = zz(i14) - dz
3119 GOSUB 2700
3120 kk(i14, j14) = kkk + kabab
3121 xx = kfo * (rr(i14) + rr(j14)) / 2
3122 fk(i14, j14) = fff + fabab
3123 yy = ff / 2 * (rr(i14) + rr(j14)) / 2
3125 GOTO 3195
3126 NEXT i31
3127 GOTO 3150
3130 REM kfod
3135 ra = rr(i14)
3136 za = zz(i14)
3138 GOSUB 2700
3140 kkk = kaaaa
3142 fff = faaaa
3143 ra = rr(i14) - dr
3144 GOSUB 2700
3145 kk(i14, j14) = kkk + kbaba
3146 xx = kfod * (rr(i14) + rr(j14)) / 2
3147 fk(i14, j14) = fff + fbaba
3148 yy = ff / 2 * (rr(i14) + rr(j14)) / 2
3149 GOTO 3195
3150 REM kf
3152 ra = rr(i14)
3156 za = zz(i14)
3157 GOSUB 2700
3158 kkk = kaaaa
3162 fff = faaaa
3165 ra = rr(i14) - dr

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```

166 za = zz(i14) - dz
3167 GOSUB 2700
170 kkk = kkk + kbbbbb
172 fff = fff + fbbbbb
3175 ra = rr(i14)
3180 GOSUB 2700
181 kkk = kkk + kabab
182 fff = fff + fabab
3183 ra = rr(i14) - dr
185 za = zz(i14)
187 GOSUB 2700
3188 kk(i14, j14) = kkk + kbaba
189 xx = kf * (rr(i14) + rr(j14)) / 2
190 fk(i14, j14) = fff + fbaba
3192 yy = ff * (rr(i14) + rr(j14)) / 2
3195 RETURN
200 REM krl and Noninteractors
205 FOR I32 = 1 TO nnn - 2
3210 IF i14 = (nnn * I32 + 1) GOTO 3223
212 GOTO 3229
223 kk(i14, j14) = 0
3224 xx = 0
225 fk(i14, j14) = 0
226 yy = 0
3228 GOTO 3285
3229 NEXT I32
230 FOR J32 = 2 TO nnn - 1
232 IF i14 = J32 GOTO 3235
3233 GOTO 3252
235 REM krlo
240 ra = rr(i14) - dr
3242 za = zz(i14)
245 GOSUB 2700
246 kk(i14, j14) = kbaaa
247 xx = krlo * (rr(i14) + rr(j14)) / 2
3248 fk(i14, j14) = fbaaa
249 yy = ff / 8 * (rr(i14) + rr(j14)) / 2
250 GOTO 3285
3252 NEXT J32
254 REM krl
256 ra = rr(i14) - dr
3258 za = zz(i14)
3260 GOSUB 2700
262 kkk = kbaaa
264 fff = fbaaa
3265 za = zz(i14) - dz
268 GOSUB 2700
270 kk(i14, j14) = kkk + kbbab
3271 xx = krl * (rr(i14) + rr(j14)) / 2
272 fk(i14, j14) = fff + fbbab
273 yy = ff / 4 * (rr(i14) + rr(j14)) / 2
3285 RETURN
3300 REM kvd on Inside
305 FOR i33 = 1 TO nnn - 1
330 IF i14 = (i33 * nnn + 1) GOTO 3335
3332 GOTO 3350
335 REM kvdo
336 ra = rr(i14)
3338 za = zz(i14) - dz
3340 GOSUB 2700

```

```

3341 kk(i14, j14) = kabaa
3342 xx = kvdo * (rr(i14) + rr(j14)) / 2
3343 fk(i14, j14) = fabaa
3344 yy = ff / 8 * (rr(i14) + rr(j14)) / 2
3345 GOTO 3385
3350 NEXT i33
3352 REM kvd
3354 ra = rr(i14)
3356 za = zz(i14) - dz
3358 GOSUB 2700
3360 kkk = kabaa
3362 fff = fabaa
3364 ra = rr(i14) - dr
3368 GOSUB 2700
3370 kk(i14, j14) = kkk + kbbba
3371 xx = kvd * (rr(i14) + rr(j14)) / 2
3372 fk(i14, j14) = fff + fbbba
3373 yy = ff / 4 * (rr(i14) + rr(j14)) / 2
3385 RETURN
3400 REM kvu on Inside and Noninteractors
3405 FOR i34 = 1 TO nnn - 2
3430 IF i14 = (i34 * nnn + 1) GOTO 3435
3432 GOTO 3452
3435 REM kvuo
3440 ra = rr(i14)
3442 za = zz(i14)
3444 GOSUB 2700
3446 kk(i14, j14) = kaaab
3447 xx = kvuo * (rr(i14) + rr(j14)) / 2
3448 fk(i14, j14) = faaab
3449 yy = ff / 8 * (rr(i14) + rr(j14)) / 2
3450 GOTO 3485
3452 NEXT i34
3454 REM kvu
3456 ra = rr(i14)
3458 za = zz(i14)
3460 GOSUB 2700
3462 kkk = kaaab
3464 fff = faaab
3466 ra = rr(i14) - dr
3468 GOSUB 2700
3470 kk(i14, j14) = kkk + kbabb
3471 xx = kvu * (rr(i14) + rr(j14)) / 2
3472 fk(i14, j14) = fff + fbabb
3474 yy = ff / 4 * (rr(i14) + rr(j14)) / 2
3485 RETURN
3500 REM Zero the kdl Elements on Inside Boundary
3505 FOR i35 = 1 TO nnn - 2
3510 IF i14 = (i35 * nnn + 1) GOTO 3520
3515 GOTO 3550
3520 kk(i14, j14) = 0
3521 xx = 0
3522 fk(i14, j14) = 0
3523 yy = 0
3525 GOTO 3585
3550 NEXT i35
3552 REM kdl
3554 ra = rr(i14) - dr
3556 za = zz(i14) - dz
3558 GOSUB 2700

```

```

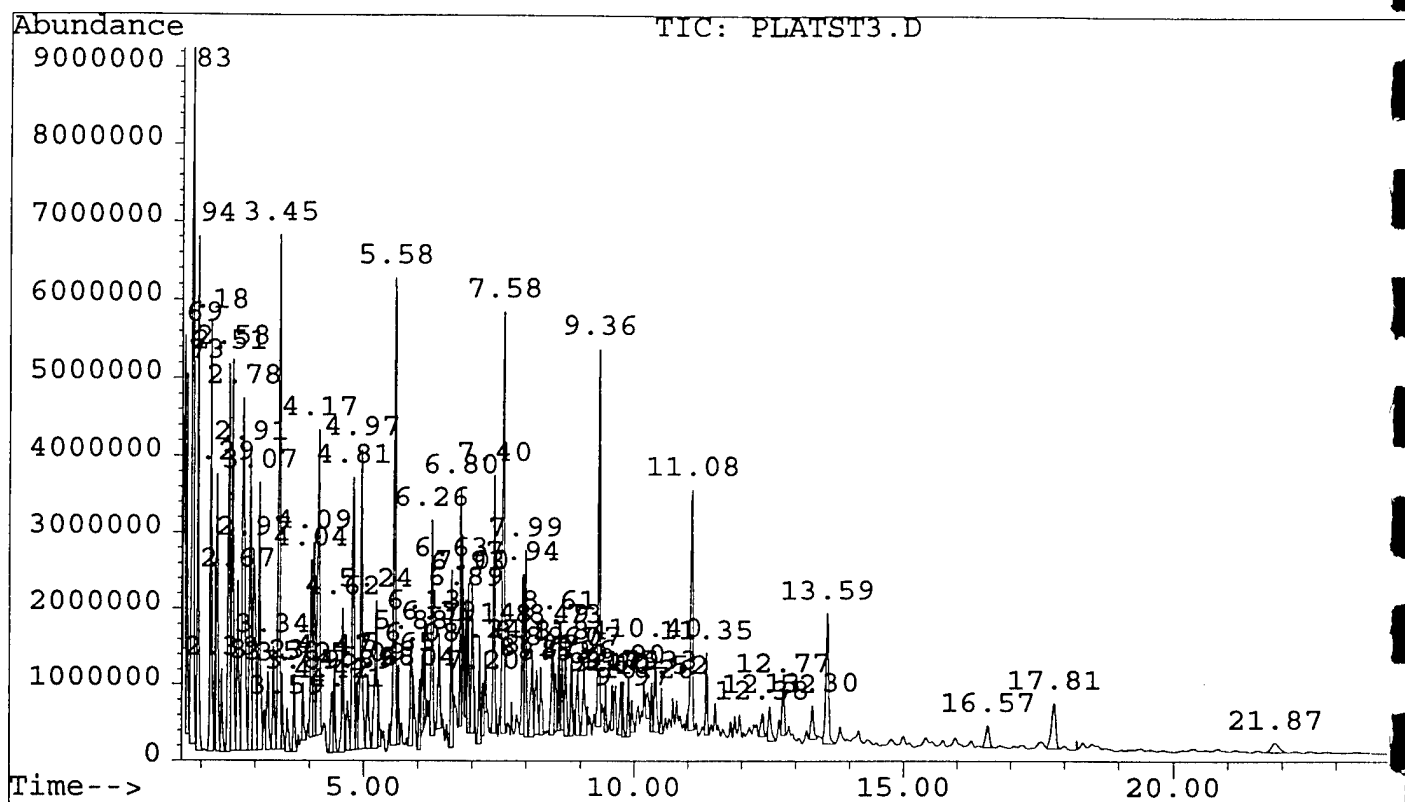
560 kk(i14, j14) = kbbaa
3561 xx = kdl * (rr(i14) + rr(j14)) / 2
562 fk(i14, j14) = fbbaa
563 yy = ff / 16 * (rr(i14) + rr(j14)) / 2
3585 RETURN
3600 REM krr on Bottom
605 FOR I36 = 2 TO nnn - 1
610 IF i14 = I36 GOTO 3635
3633 GOTO 3650
635 REM krro
636 ra = rr(i14)
3638 za = zz(i14)
640 GOSUB 2700
642 kk(i14, j14) = kaaba
3643 xx = krro * (rr(i14) + rr(j14)) / 2
3644 fk(i14, j14) = faaba
645 yy = ff / 8 * (rr(i14) + rr(j14)) / 2
648 GOTO 3695
3650 NEXT I36
653 REM krr
654 ra = rr(i14)
3656 za = zz(i14)
657 GOSUB 2700
658 kkk = kaaba
660 fff = faaba
3661 ra = rr(i14)
664 za = zz(i14) - dz
665 GOSUB 2700
3666 kk(i14, j14) = kkk + kabbb
668 xx = krr * (rr(i14) + rr(j14)) / 2
670 fk(i14, j14) = fff + fabbb
3672 yy = ff / 4 * (rr(i14) + rr(j14)) / 2
3695 RETURN
700 REM Zero the kul Elements on Inside Boundary
705 FOR i37 = 1 TO nnn - 1
3710 IF i14 = (i37 * nnn + 1) GOTO 3720
715 GOTO 3750
720 kk(i14, j14) = 0
3721 xx = 0
722 fk(i14, j14) = 0
723 yy = 0
3725 GOTO 3785
3750 NEXT i37
752 REM kul
755 ra = rr(i14) - dr
3756 za = zz(i14)
757 GOSUB 2700
759 kk(i14, j14) = kbaab
3760 xx = kul * (rr(i14) + rr(j14)) / 2
761 fk(i14, j14) = fbaab
762 yy = ff / 16 * (rr(i14) + rr(j14)) / 2
3785 RETURN
4600 REM kur
605 ra = rr(i14)
610 za = zz(i14)
4615 GOSUB 2700
620 kk(i14, j14) = kaabb
625 xx = kur * (rr(i14) + rr(j14)) / 2
4650 fk(i14, j14) = faabb
4652 yy = ff / 16 * (rr(i14) + rr(j14)) / 2

```

```
4685 RETURN
4700 REM kdr
4705 ra = rr(i14)
4710 za = zz(i14) - dz
4715 GOSUB 2700
4720 kk(i14, j14) = kabba
4725 xx = kdr * (rr(i14) + rr(j14)) / 2
4750 fk(i14, j14) = fabba
4755 yy = ff / 16 * (rr(i14) + rr(j14)) / 2
4752 RETURN
```

APPENDIX VI GCD OUTPUT FOR SEPARATE PHASE ANALYSIS

File : C:\HPCHEM\1\DATA\PLATST3.D
Operator :
Acquired : 13 Dec 95 1:48 pm using AcqMethod PLATFAZE
Instrument : GCD
Sample Name:
Misc Info :
Vial Number: 1



Summary Library Search Report

Information from Data File:

: C:\HPCHEM\1\DATA\PLATST3.D
 ator :
 ired : 13 Dec 95 1:48 pm using AcqMethod PLATFAZE
 le Name:
 Info :
 Number: 1

ch Libraries: C:\DATABASE\NBS75K.L Minimum Quality: 0

own Spectrum: Apex minus start of peak
 gration Params: current RTEINT parameters

| RT | Area% | Library/ID | Ref# | CAS# | Qual |
|------|-------|--------------------------------|-------|-------------|------|
| 1.69 | 1.83 | C:\DATABASE\NBS75K.L | | | |
| | | Pentane, 2,3-dimethyl- | 63429 | 000565-59-3 | 87 |
| | | Heptane | 1600 | 000142-82-5 | 64 |
| | | 1-Pentanol, 2,3-dimethyl- | 3343 | 010143-23-4 | 59 |
| 1.73 | 1.72 | C:\DATABASE\NBS75K.L | | | |
| | | Hexane, 3-methyl- | 63421 | 000589-34-4 | 87 |
| | | Pentane, 3-ethyl- | 1595 | 000617-78-7 | 87 |
| | | Hexane, 2,3-dimethyl- | 3097 | 000584-94-1 | 64 |
| 1.83 | 4.99 | C:\DATABASE\NBS75K.L | | | |
| | | Butane, 2,2,3,3-tetramethyl- | 64215 | 000594-82-1 | 78 |
| | | Hexane, 2,2-dimethyl- | 64217 | 000590-73-8 | 78 |
| | | Heptane, 2,2,4-trimethyl- | 8105 | 014720-74-2 | 72 |
| 1.94 | 3.14 | C:\DATABASE\NBS75K.L | | | |
| | | Heptane | 63440 | 000142-82-5 | 93 |
| | | Hexane, 3-methyl- | 1593 | 000589-34-4 | 62 |
| | | Pentane, 3-ethyl- | 63426 | 000617-78-7 | 38 |
| 2.18 | 2.91 | C:\DATABASE\NBS75K.L | | | |
| | | Cyclohexane, methyl- | 1326 | 000108-87-2 | 96 |
| | | 2-Pentene, 4,4-dimethyl-, (E)- | 1344 | 000690-08-4 | 70 |
| | | 2-Pentene, 2,4-dimethyl- | 63270 | 000625-65-0 | 70 |

| | | | | | |
|------|------|---------------------------------------|-------|-------------|----|
| 2.29 | 2.07 | C:\DATABASE\NBS75K.L | | | |
| | | Hexane, 3,4-dimethyl- | 64210 | 000583-48-2 | 78 |
| | | Butane, 2,2,3-trimethyl- | 63437 | 000464-06-2 | 53 |
| | | Hexane, 2,4-dimethyl- | 3089 | 000589-43-5 | 50 |
| 2.39 | 0.52 | C:\DATABASE\NBS75K.L | | | |
| | | Cyclopentane, 1,2,4-trimethyl- | 2680 | 002815-58-9 | 78 |
| | | Cyclopentane, 1,2,4-trimethyl-, (1.al | 2684 | 004850-28-6 | 74 |
| | | Undecane, 3-methylene- | 14736 | 071138-64-2 | 72 |
| 2.51 | 3.00 | C:\DATABASE\NBS75K.L | | | |
| | | Pentane, 2,3,4-trimethyl- | 3100 | 000565-75-3 | 90 |
| | | Hexane, 2,3-dimethyl- | 3097 | 000584-94-1 | 87 |
| | | Heptane, 4-methyl- | 3096 | 000589-53-7 | 74 |
| 2.58 | 2.79 | C:\DATABASE\NBS75K.L | | | |
| | | Pentane, 2,3,3-trimethyl- | 3088 | 000560-21-4 | 90 |
| | | Hexane, 2,3,4-trimethyl- | 5147 | 000921-47-1 | 64 |
| | | Hexane, 3-methyl- | 1593 | 000589-34-4 | 64 |
| 2.67 | 1.41 | C:\DATABASE\NBS75K.L | | | |
| | | Hexane, 2,3-dimethyl- | 64226 | 000584-94-1 | 78 |
| | | Heptane, 4-methyl- | 64224 | 000589-53-7 | 64 |
| | | Pentane, 3-ethyl- | 1595 | 000617-78-7 | 64 |
| 2.78 | 3.79 | C:\DATABASE\NBS75K.L | | | |
| | | Heptane, 2-methyl- | 64219 | 000592-27-8 | 95 |
| | | Hexane, 2,5-dimethyl- | 64204 | 000592-13-2 | 53 |
| | | Pentane, 2-methyl- | 62863 | 000107-83-5 | 50 |
| 2.91 | 2.39 | C:\DATABASE\NBS75K.L | | | |
| | | Heptane, 3-methyl- | 64227 | 000589-81-1 | 91 |
| | | Octane, 3,4-dimethyl- | 8107 | 015869-92-8 | 72 |
| | | Hexane, 2,4-dimethyl- | 64213 | 000589-43-5 | 68 |
| 2.97 | 1.91 | C:\DATABASE\NBS75K.L | | | |
| | | Cyclohexane, 1,3-dimethyl-, cis- | 64018 | 000638-04-0 | 95 |
| | | Cyclohexane, 1,3-dimethyl- | 2687 | 000591-21-9 | 94 |
| | | Cyclohexane, 1,4-dimethyl-, trans- | 2668 | 002207-04-7 | 91 |
| 3.07 | 2.16 | C:\DATABASE\NBS75K.L | | | |

| | | | | | |
|------|------|---------------------------------------|-------|-------------|----|
| | | Hexane, 2,2,5-trimethyl- | 65126 | 003522-94-9 | 83 |
| | | Hexane, 2,2,4-trimethyl- | 5131 | 016747-26-5 | 78 |
| | | Hexane, 2,2,5,5-tetramethyl- | 66226 | 001071-81-4 | 72 |
| 3.23 | 0.73 | C:\DATABASE\NBS75K.L | | | |
| | | Cyclopentane, 1-ethyl-2-methyl-, cis- | 2670 | 000930-89-2 | 93 |
| | | Cyclopentane, 1-ethyl-3-methyl-, tran | 2698 | 002613-65-2 | 90 |
| | | Cyclopentane, 1-ethyl-3-methyl- | 2696 | 003726-47-4 | 90 |
| 3.34 | 0.76 | C:\DATABASE\NBS75K.L | | | |
| | | Cyclohexane, 1,3-dimethyl-, trans- | 64001 | 002207-03-6 | 94 |
| | | Cyclohexane, 1,2-dimethyl-, trans- | 64014 | 006876-23-9 | 94 |
| | | Cyclohexane, 1,4-dimethyl- | 64013 | 000589-90-2 | 91 |
| 3.45 | 4.10 | C:\DATABASE\NBS75K.L | | | |
| | | Octane | 3084 | 000111-65-9 | 90 |
| | | Hexane, 2,4-dimethyl- | 3089 | 000589-43-5 | 64 |
| | | Ether, hexyl pentyl | 15858 | 032357-83-8 | 59 |
| 3.50 | 0.43 | C:\DATABASE\NBS75K.L | | | |
| | | Cyclohexane, 1,3-dimethyl-, cis- | 64018 | 000638-04-0 | 95 |
| | | Cyclohexane, 1,3-dimethyl-, trans- | 2661 | 002207-03-6 | 91 |
| | | Cyclohexane, 1,4-dimethyl-, cis- | 2704 | 000624-29-3 | 91 |
| 3.59 | 0.37 | C:\DATABASE\NBS75K.L | | | |
| | | Tetrachloroethylene | 13222 | 000127-18-4 | 99 |
| | | Pyrimidine, 5-fluoro-2,4-dichloro- | 13787 | 002927-71-1 | 16 |
| | | 2-Chloroquinoxaline | 13329 | 001448-87-9 | 16 |
| 3.72 | 0.53 | C:\DATABASE\NBS75K.L | | | |
| | | Hexane, 2,3,5-trimethyl- | 65140 | 001069-53-0 | 90 |
| | | Heptane, 2,4-dimethyl- | 65120 | 002213-23-2 | 81 |
| | | Pentane, 3-ethyl-2,4-dimethyl- | 5138 | 001068-87-7 | 78 |
| 3.89 | 0.38 | C:\DATABASE\NBS75K.L | | | |
| | | Heptane, 2,4-dimethyl- | 65120 | 002213-23-2 | 91 |
| | | Dodecane, 5-methyl- | 19034 | 017453-93-9 | 59 |
| | | Hexane, 2,4-dimethyl- | 3089 | 000589-43-5 | 59 |
| 4.04 | 1.48 | C:\DATABASE\NBS75K.L | | | |
| | | Heptane, 2,6-dimethyl- | 5156 | 001072-05-5 | 94 |
| | | Octane, 2-methyl- | 65117 | 003221-61-2 | 90 |

| | | | | | |
|------|------|---------------------------------------|-------|-------------|----|
| | | Dodecane | 68249 | 000112-40-3 | 64 |
| 4.09 | 1.23 | C:\DATABASE\NBS75K.L | | | |
| | | Cyclohexane, ethyl- | 64006 | 001678-91-7 | 90 |
| | | Cyclohexane, undecyl- | 31654 | 054105-66-7 | 64 |
| | | Cyclohexane, octyl- | 21971 | 001795-15-9 | 56 |
| 4.17 | 2.57 | C:\DATABASE\NBS75K.L | | | |
| | | Cyclohexane, 1,1,3-trimethyl- | 64942 | 003073-66-3 | 50 |
| | | Cyclohexane, 1,3,5-trimethyl-, (1.alp | 4669 | 001795-27-3 | 47 |
| | | Cyclooctane, butyl- | 14729 | 016538-93-5 | 43 |
| 4.42 | 0.59 | C:\DATABASE\NBS75K.L | | | |
| | | 1-Nonene | 64956 | 000124-11-8 | 43 |
| | | 1-Heptanol, 4-methyl- | 5564 | 000817-91-4 | 43 |
| | | Cyclopentane, 1,3-dimethyl-, trans- | 1329 | 001759-58-6 | 43 |
| 4.47 | 0.58 | C:\DATABASE\NBS75K.L | | | |
| | | Cyclohexane, 1,3,5-trimethyl-, (1.alp | 64953 | 001795-27-3 | 91 |
| | | Cyclohexane, 1,3,5-trimethyl- | 64930 | 001839-63-0 | 91 |
| | | Cyclohexane, 1,1,3-trimethyl- | 4647 | 003073-66-3 | 64 |
| 4.62 | 1.15 | C:\DATABASE\NBS75K.L | | | |
| | | Heptane, 2,3-dimethyl- | 65133 | 003074-71-3 | 86 |
| | | Hexane, 3-ethyl-2-methyl- | 5160 | 016789-46-1 | 80 |
| | | Decane, 5,6-dimethyl- | 15355 | 001636-43-7 | 72 |
| 4.71 | 0.47 | C:\DATABASE\NBS75K.L | | | |
| | | Ethylbenzene | 63691 | 000100-41-4 | 91 |
| | | p-Xylene | 63700 | 000106-42-3 | 50 |
| | | Benzene, 1,3-dimethyl- | 2027 | 000108-38-3 | 43 |
| 4.81 | 2.57 | C:\DATABASE\NBS75K.L | | | |
| | | Octane, 2-methyl- | 5142 | 003221-61-2 | 91 |
| | | Heptane, 2,6-dimethyl- | 65137 | 001072-05-5 | 90 |
| | | Decane, 2,9-dimethyl- | 15361 | 001002-17-1 | 72 |
| 4.89 | 0.43 | C:\DATABASE\NBS75K.L | | | |
| | | Benzene, 1,3-dimethyl- | 63695 | 000108-38-3 | 97 |
| | | Benzene, 1,2-dimethyl- | 63707 | 000095-47-6 | 97 |
| | | p-Xylene | 63702 | 000106-42-3 | 97 |

| | | | | | |
|------|------|---------------------------------------|-------|-------------|----|
| 4.97 | 2.46 | C:\DATABASE\NBS75K.L | | | |
| | | Octane, 3-methyl- | 65130 | 002216-33-3 | 87 |
| | | Decane, 5-methyl- | 11605 | 013151-35-4 | 53 |
| | | Heptane, 2,5-dimethyl- | 5143 | 002216-30-0 | 53 |
| 5.09 | 0.66 | C:\DATABASE\NBS75K.L | | | |
| | | 2-Pyrrolidinone, 1-ethenyl- | 63902 | 000088-12-0 | 50 |
| | | Pentane, 3-ethyl-2,2-dimethyl- | 5136 | 016747-32-3 | 47 |
| | | Cyclohexane, 1,1,2-trimethyl- | 64970 | 007094-26-0 | 46 |
| 5.24 | 1.68 | C:\DATABASE\NBS75K.L | | | |
| | | 1-Ethyl-3-methylcyclohexane (c,t) | 4658 | 003728-55-0 | 81 |
| | | cis-1-Ethyl-3-methyl-cyclohexane | 4636 | 019489-10-2 | 81 |
| | | Cyclohexane, 1-ethyl-2-methyl-, trans | 4650 | 004923-78-8 | 70 |
| 5.28 | 0.33 | C:\DATABASE\NBS75K.L | | | |
| | | Cyclohexane, 1-ethyl-4-methyl-, trans | 64955 | 006236-88-0 | 83 |
| | | Cyclohexane, 1-methyl-4-(1-methylethy | 66078 | 006069-98-3 | 78 |
| | | Cyclohexane, 1-ethyl-4-methyl-, cis- | 64934 | 004926-78-7 | 64 |
| 5.58 | 4.01 | C:\DATABASE\NBS75K.L | | | |
| | | Nonane | 65142 | 000111-84-2 | 87 |
| | | 1-Octanol, 2-butyl- | 69110 | 003913-02-8 | 59 |
| | | Octane | 64207 | 000111-65-9 | 59 |
| 5.65 | 0.41 | C:\DATABASE\NBS75K.L | | | |
| | | Cyclohexane, 1-bromo-3-methyl- | 16582 | 013905-48-1 | 64 |
| | | Cyclohexane, 1-bromo-4-methyl- | 16585 | 006294-40-2 | 64 |
| | | cis-1-Ethyl-3-methyl-cyclohexane | 4636 | 019489-10-2 | 52 |
| 5.88 | 0.83 | C:\DATABASE\NBS75K.L | | | |
| | | Bicyclo[3.3.1]nonane | 64809 | 000280-65-9 | 76 |
| | | Pentalene, octahydro-2-methyl- | 4274 | 003868-64-2 | 64 |
| | | Bicyclo[4.1.0]heptane | 63134 | 000286-08-8 | 58 |
| 6.04 | 0.45 | C:\DATABASE\NBS75K.L | | | |
| | | Benzene, (1-methylethyl)- | 64555 | 000098-82-8 | 93 |
| | | Benzene, 1,2,3-trimethyl- | 3773 | 000526-73-8 | 80 |
| | | Benzene, 1-ethyl-2-methyl- | 64558 | 000611-14-3 | 72 |
| 6.08 | 0.47 | C:\DATABASE\NBS75K.L | | | |
| | | 1-Decanol, 2-ethyl- | 19527 | 021078-65-9 | 59 |

| | | | | | |
|------|------|---------------------------------------|-------|-------------|----|
| | | Octane, 3,5-dimethyl- | 66229 | 015869-93-9 | 49 |
| | | Hexane, 3-ethyl-4-methyl- | 5162 | 003074-77-9 | 47 |
| 6.13 | 0.55 | C:\DATABASE\NBS75K.L | | | |
| | | Cyclohexane, (1-methylethyl)- | 4682 | 000696-29-7 | 91 |
| | | Cyclohexane, propyl- | 4637 | 001678-92-8 | 90 |
| | | Cyclohexane, hexyl- | 68123 | 004292-75-5 | 72 |
| 6.26 | 1.43 | C:\DATABASE\NBS75K.L | | | |
| | | Octane, 3,6-dimethyl- | 8109 | 015869-94-0 | 90 |
| | | Nonane, 3-methyl- | 66200 | 005911-04-6 | 90 |
| | | Octane, 2,6-dimethyl- | 8103 | 002051-30-1 | 80 |
| 6.39 | 0.78 | C:\DATABASE\NBS75K.L | | | |
| | | Heptane, 3-ethyl-2-methyl- | 8080 | 014676-29-0 | 72 |
| | | Heptane, 4-(1-methylethyl)- | 8084 | 052896-87-4 | 47 |
| | | Undecane, 5,6-dimethyl- | 19004 | 017615-91-7 | 47 |
| 6.63 | 1.16 | C:\DATABASE\NBS75K.L | | | |
| | | Benzene, propyl- | 3781 | 000103-65-1 | 83 |
| | | 1,2-Ethanediamine, N,N'-bis(phenylmet | 32052 | 000140-28-3 | 25 |
| | | Propanenitrile, 3-[(phenylmethyl)amin | 12493 | 000706-03-6 | 25 |
| 6.80 | 1.67 | C:\DATABASE\NBS75K.L | | | |
| | | Benzene, 1-ethyl-3-methyl- | 64563 | 000620-14-4 | 93 |
| | | Benzene, 1-ethyl-2-methyl- | 64559 | 000611-14-3 | 93 |
| | | Benzene, 1-ethyl-4-methyl- | 3770 | 000622-96-8 | 93 |
| 6.89 | 0.56 | C:\DATABASE\NBS75K.L | | | |
| | | Nonane, 2-methyl- | 66220 | 000871-83-0 | 91 |
| | | Octane, 2,7-dimethyl- | 66209 | 001072-16-8 | 78 |
| | | Decane | 66205 | 000124-18-5 | 72 |
| 6.93 | 0.82 | C:\DATABASE\NBS75K.L | | | |
| | | Benzene, 1,2,3-trimethyl- | 64573 | 000526-73-8 | 95 |
| | | 1,2,4-Trimethylbenzene | 3771 | 000095-36-3 | 95 |
| | | Benzene, 1,3,5-trimethyl- | 64569 | 000108-67-8 | 94 |
| 7.00 | 0.96 | C:\DATABASE\NBS75K.L | | | |
| | | Nonane, 3-methyl- | 66200 | 005911-04-6 | 70 |
| | | Octane, 4,5-dimethyl- | 8076 | 015869-96-2 | 38 |
| | | Octane, 2,3,7-trimethyl- | 11603 | 062016-34-6 | 38 |

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|------|------|--|-------|-------------|----|
| 7.14 | 0.67 | C:\DATABASE\NBS75K.L | | | |
| | | Benzene, 1-ethyl-2-methyl- | 3765 | 000611-14-3 | 94 |
| | | Benzene, 1,3,5-trimethyl- | 64570 | 000108-67-8 | 91 |
| | | Benzene, (1-methylethyl)- | 64553 | 000098-82-8 | 91 |
| 7.20 | 0.31 | C:\DATABASE\NBS75K.L | | | |
| | | Cyclohexane, 1-methyl-4-(1-methylethyl)- | 7600 | 001678-82-6 | 74 |
| | | Cyclohexane, 1-methyl-3-propyl- | 7596 | 004291-80-9 | 72 |
| | | Cyclohexane, 1-methyl-2-propyl- | 7590 | 004291-79-6 | 72 |
| 7.24 | 0.32 | C:\DATABASE\NBS75K.L | | | |
| | | 1-Methyl-4-(1-methylethyl)-cyclohexan | 66083 | 000099-82-1 | 45 |
| | | Cyclohexane, 1-methyl-4-(1-methylethyl)- | 66079 | 001678-82-6 | 43 |
| | | Cyclohexane, 1-methyl-4-(1-methylethyl)- | 66077 | 006069-98-3 | 41 |
| 7.40 | 1.67 | C:\DATABASE\NBS75K.L | | | |
| | | Benzene, 1,2,3-trimethyl- | 64573 | 000526-73-8 | 94 |
| | | Benzene, 1,3,5-trimethyl- | 64569 | 000108-67-8 | 94 |
| | | Benzene, 1,2,4-trimethyl- | 64577 | 000095-63-6 | 94 |
| 7.58 | 2.87 | C:\DATABASE\NBS75K.L | | | |
| | | Decane | 66205 | 000124-18-5 | 97 |
| | | Undecane | 67317 | 001120-21-4 | 86 |
| | | Heneicosane | 72684 | 000629-94-7 | 83 |
| 7.94 | 1.14 | C:\DATABASE\NBS75K.L | | | |
| | | 1,2,4-Trimethylbenzene | 3771 | 000095-36-3 | 94 |
| | | Benzene, 1,2,3-trimethyl- | 64576 | 000526-73-8 | 93 |
| | | Benzene, 1,2,4-trimethyl- | 3775 | 000095-63-6 | 93 |
| 7.99 | 1.21 | C:\DATABASE\NBS75K.L | | | |
| | | Decane, 4-methyl- | 67323 | 002847-72-5 | 94 |
| | | Nonane, 2,6-dimethyl- | 11598 | 017302-28-2 | 91 |
| | | Octane, 2,3,6-trimethyl- | 11602 | 062016-33-5 | 78 |
| 8.11 | 0.73 | C:\DATABASE\NBS75K.L | | | |
| | | Cyclohexane, butyl- | 66057 | 001678-93-9 | 93 |
| | | Cyclohexane, ethyl- | 64006 | 001678-91-7 | 83 |
| | | Cyclohexane, propyl- | 64935 | 001678-92-8 | 80 |
| 8.19 | 0.69 | C:\DATABASE\NBS75K.L | | | |

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|------|------|---------------------------------------|-------|-------------|----|
| | | Decane, 3-methyl- | 67315 | 013151-34-3 | 70 |
| | | Hexadecane | 70787 | 000544-76-3 | 49 |
| | | Dotriacontane | 74490 | 000544-85-4 | 47 |
| 8.27 | 0.53 | C:\DATABASE\NBS75K.L | | | |
| | | Decane, 3-methyl- | 67315 | 013151-34-3 | 87 |
| | | Nonane, 3,7-dimethyl- | 11601 | 017302-32-8 | 59 |
| | | Nonane, 3-methyl- | 66203 | 005911-04-6 | 47 |
| 8.49 | 0.85 | C:\DATABASE\NBS75K.L | | | |
| | | Benzene, 1-methyl-3-propyl- | 6195 | 001074-43-7 | 90 |
| | | Benzene, 1-methyl-2-propyl- | 6230 | 001074-17-5 | 55 |
| | | Benzene, (1-methylpropyl)- | 65543 | 000135-98-8 | 50 |
| 8.53 | 0.46 | C:\DATABASE\NBS75K.L | | | |
| | | Benzene, 1-methyl-2-propyl- | 65584 | 001074-17-5 | 92 |
| | | Benzene, 1-methyl-4-propyl- | 6216 | 001074-55-1 | 70 |
| | | Benzene, (1-methylpropyl)- | 65543 | 000135-98-8 | 62 |
| 8.61 | 0.52 | C:\DATABASE\NBS75K.L | | | |
| | | Decane, 5-methyl- | 11605 | 013151-35-4 | 70 |
| | | Benzene, 1-methyl-4-(1-methylethyl)- | 6201 | 000099-87-6 | 64 |
| | | Benzene, 4-ethyl-1,2-dimethyl- | 65568 | 000934-80-5 | 64 |
| 8.67 | 0.41 | C:\DATABASE\NBS75K.L | | | |
| | | Decane, 4-methyl- | 11615 | 002847-72-5 | 97 |
| | | Decane, 2,6,7-trimethyl- | 19027 | 062108-25-2 | 78 |
| | | 1,2-Cyclohexanediol, 1-methyl-, trans | 5409 | 019534-08-8 | 72 |
| 8.73 | 0.75 | C:\DATABASE\NBS75K.L | | | |
| | | Decane, 2-methyl- | 67320 | 006975-98-0 | 93 |
| | | Undecane, 5-methyl- | 15363 | 001632-70-8 | 72 |
| | | Tridecane | 69019 | 000629-50-5 | 64 |
| 8.84 | 0.47 | C:\DATABASE\NBS75K.L | | | |
| | | Decane, 3-methyl- | 67314 | 013151-34-3 | 97 |
| | | Nonane, 3,7-dimethyl- | 11601 | 017302-32-8 | 83 |
| | | Nonane, 5-(2-methylpropyl)- | 19015 | 062185-53-9 | 64 |
| 8.96 | 0.62 | C:\DATABASE\NBS75K.L | | | |
| | | Benzene, 4-ethyl-1,2-dimethyl- | 65568 | 000934-80-5 | 91 |
| | | Benzene, 1,2,3,5-tetramethyl- | 6220 | 000527-53-7 | 91 |

Benzene, 1-methyl-4-(1-methylethyl)- 65534 000099-87-6 91

9.07 0.75 C:\DATABASE\NBS75K.L
 Benzene, 1,2,3,4-tetramethyl- 65540 000488-23-3 83
 Benzene, 1,2,4,5-tetramethyl- 65575 000095-93-2 83
 Benzene, 1-methyl-4-(1-methylethyl)- 65534 000099-87-6 81

9.36 2.39 C:\DATABASE\NBS75K.L
 Undecane 67317 001120-21-4 96
 Tridecane 69020 000629-50-5 90
 Undecane, 2,3-dimethyl- 18990 017312-77-5 83

9.47 0.28 C:\DATABASE\NBS75K.L
 Naphthalene, decahydro-2-methyl- 67009 002958-76-1 90
 Cyclohexanone, 5-methyl-2-(1-methylethyl)- 10356 015932-80-6 76
 1-Dodecyne 68014 000765-03-7 74

9.60 0.34 C:\DATABASE\NBS75K.L
 Benzene, 1-methyl-4-(1-methylethyl)- 65535 000099-87-6 91
 Benzene, 1,2,4,5-tetramethyl- 65576 000095-93-2 91
 Benzene, 2-ethyl-1,4-dimethyl- 65570 001758-88-9 70

9.75 0.36 C:\DATABASE\NBS75K.L
 Naphthalene, decahydro-2-methyl- 67008 002958-76-1 90
 Bicyclo[4.1.0]heptan-3-one, 4,7,7-tri 10380 004176-04-9 60
 Bicyclo[2.2.1]heptan-2-one, 1,7,7-tri 66961 000464-48-2 58

9.79 0.31 C:\DATABASE\NBS75K.L
 Undecane, 3,8-dimethyl- 19009 017301-30-3 83
 Undecane, 4,7-dimethyl- 19020 017301-32-5 78
 Undecane, 4-methyl- 15354 002980-69-0 68

9.90 0.34 C:\DATABASE\NBS75K.L
 n-Amylcyclohexane 11054 029949-27-7 90
 Cyclohexane, pentyl- 11044 004292-92-6 87
 Cyclohexane, (1-methylethyl)- 64963 000696-29-7 74

9.97 0.25 C:\DATABASE\NBS75K.L
 Cyclopentane, pentyl- 7536 003741-00-2 38
 Cyclopentane, butyl- 64938 002040-95-1 35
 Cyclopentane, (1-methylethyl)- 2707 003875-51-2 30

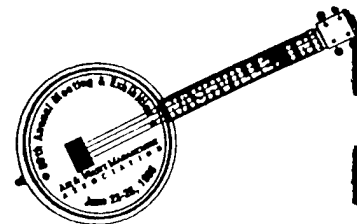
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|-------|------|-------------------------------|-------|-------------|----|
| 10.26 | 0.26 | C:\DATABASE\NBS75K.L | | | |
| | | Decane, 3,6-dimethyl- | 15348 | 017312-53-7 | 52 |
| | | 1-Iodo-2-methylnonane | 37255 | 000000-00-0 | 49 |
| | | Octane, 3-ethyl-2,7-dimethyl- | 15359 | 062183-55-5 | 47 |
| 10.33 | 0.29 | C:\DATABASE\NBS75K.L | | | |
| | | Undecane, 4-methyl- | 15354 | 002980-69-0 | 58 |
| | | Undecane, 4,8-dimethyl- | 19026 | 017301-33-6 | 47 |
| | | Dodecane, 2,6,10-trimethyl- | 25995 | 003891-98-3 | 38 |
| 10.40 | 0.60 | C:\DATABASE\NBS75K.L | | | |
| | | Undecane, 2-methyl- | 15356 | 007045-71-8 | 95 |
| | | Decane, 2,9-dimethyl- | 15361 | 001002-17-1 | 72 |
| | | Undecane, 5-methyl- | 15363 | 001632-70-8 | 58 |
| 10.52 | 0.28 | C:\DATABASE\NBS75K.L | | | |
| | | Undecane, 3-methyl- | 15362 | 001002-43-3 | 78 |
| | | Decane, 3,8-dimethyl- | 68255 | 017312-55-9 | 76 |
| | | Undecane, 5-methyl- | 15363 | 001632-70-8 | 64 |
| 11.08 | 1.91 | C:\DATABASE\NBS75K.L | | | |
| | | Dodecane | 68254 | 000112-40-3 | 95 |
| | | Tridecane | 69019 | 000629-50-5 | 91 |
| | | Hexadecane | 70787 | 000544-76-3 | 90 |
| 11.35 | 0.62 | C:\DATABASE\NBS75K.L | | | |
| | | Undecane, 2,6-dimethyl- | 69033 | 017301-23-4 | 96 |
| | | Dodecane, 6-methyl- | 19006 | 006044-71-9 | 94 |
| | | Undecane, 3,6-dimethyl- | 19000 | 017301-28-9 | 90 |
| 12.38 | 0.28 | C:\DATABASE\NBS75K.L | | | |
| | | Dodecane, 4-methyl- | 19025 | 006117-97-1 | 95 |
| | | 3-Octen-2-one, 7-methyl- | 7459 | 033046-81-0 | 53 |
| | | Pentane, 2,3,4-trimethyl- | 3100 | 000565-75-3 | 30 |
| 12.52 | 0.41 | C:\DATABASE\NBS75K.L | | | |
| | | Dodecane, 2-methyl- | 19039 | 001560-97-0 | 72 |
| | | Tetradecane, 2-methyl- | 70279 | 001560-95-8 | 64 |
| | | Decane, 2-methyl- | 67320 | 006975-98-0 | 59 |
| 12.77 | 0.42 | C:\DATABASE\NBS75K.L | | | |
| | | Dodecane, 4,6-dimethyl- | 69666 | 061141-72-8 | 83 |

| | | | | | |
|-------|------|-----------------------------|-------|-------------|----|
| | | Tridecane, 4-methyl- | 69665 | 026730-12-1 | 72 |
| | | Octane, 2,3,7-trimethyl- | 11603 | 062016-34-6 | 72 |
| 13.30 | 0.37 | C:\DATABASE\NBS75K.L | | | |
| | | Naphthalene, 2-methyl- | 66236 | 000091-57-6 | 94 |
| | | Naphthalene, 1-methyl- | 66231 | 000090-12-0 | 91 |
| | | Benzocycloheptatriene | 8114 | 000264-09-5 | 90 |
| 13.59 | 1.55 | C:\DATABASE\NBS75K.L | | | |
| | | Tridecane | 69019 | 000629-50-5 | 97 |
| | | Hexadecane | 70789 | 000544-76-3 | 90 |
| | | Dodecane | 68249 | 000112-40-3 | 90 |
| 16.57 | 0.35 | C:\DATABASE\NBS75K.L | | | |
| | | Dodecane, 2,6,11-trimethyl- | 25998 | 031295-56-4 | 86 |
| | | Dodecane, 2,7,10-trimethyl- | 26005 | 074645-98-0 | 80 |
| | | Dodecane, 2,6,10-trimethyl- | 25995 | 003891-98-3 | 80 |
| 17.81 | 0.86 | C:\DATABASE\NBS75K.L | | | |
| | | Tetradecane | 69658 | 000629-59-4 | 91 |
| | | Tridecane | 69019 | 000629-50-5 | 91 |
| | | Hexadecane | 70789 | 000544-76-3 | 90 |
| 21.87 | 0.31 | C:\DATABASE\NBS75K.L | | | |
| | | Tetradecane | 69661 | 000629-59-4 | 80 |
| | | Decane, 5-propyl- | 19035 | 017312-62-8 | 72 |
| | | Dodecane, 2,6,10-trimethyl- | 70270 | 003891-98-3 | 72 |

Wed Dec 13 14:21:49 1995

**APPENDIX VII EMISSIONS ISOLATION FLUX
CHAMBER**

1996 Annual Meeting Abstract Form



Paper No. 96-TP40.01

Paper Title Evaluation of Surface Emissions from Bioventing Sites

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Bioventing has become a popular means of remediating hazardous waste sites contaminated with aerobically biodegradable volatile organic compounds (VOCs). Bioventing systems can operate under positive or negative pressure. Positive pressure systems may have advantages with regard to treatment efficiency by forcing VOCs and oxygen through the microbially active rhizosphere. Emissions from positive pressure bioventing systems, however, can pose health and regulatory concerns and may also overstate the effectiveness of the process.

This paper investigates two proposed methods of quantifying air impacts from a bioventing site at a former air force base in Plattsburgh, New York, contaminated with VOCs. The first method uses a modified version of an enclosed isolation flux chamber (EIFC) design developed for the EPA. The EIFC is placed over the soil to be sampled, allowing a direct measurement of VOC flux from the soil. For this study, the EIFC collection method was modified from the EPA design to compensate for advective flux.

The second method utilizes a low volume soil gas probe which is used to obtain a vertically resolved profile of vapor phase contaminant concentrations in the near surface soil zone. The soil gas profiler (SGP) permits the extraction of small volume samples of soil gas at regular intervals from ground level to 45 cm below the surface. The resolved vertical profiles of such soil gas constituents as VOCs, oxygen, carbon dioxide, and conservative tracers document biotic and abiotic transport processes through the rhizosphere. The contaminant flux can be calculated from these profiles when combined with mathematical models of fate and transport of gases and vapors in porous media.

A laboratory evaluation of the EIFC and SGP methods was conducted under controlled conditions using a mesoscale bioventing system and helium as a conservative tracer. Mixing characteristics of the EIFC were evaluated and sweep gas flow rate and sampling times were optimized. A calibrated flux was determined using resolved vertical profiles obtained with the SGP and a simple transport model. Helium flux was also measured directly using the EIFC. Results indicate a slight underprediction of mass flux but consistent agreement between EIFC and SGP methods.

Evaluation of Surface Emissions from Bioventing Sites

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INTRODUCTION

Bioventing is an attractive means of remediating hazardous waste sites contaminated with volatile organic compounds (VOCs). For aerobically biodegradable VOCs, advantages of bioventing include low cost and the ability to degrade contaminants to carbon dioxide and water.

Bioventing systems can operate under either negative or positive pressure. In negative pressure systems, a vacuum is applied to the subsurface to induce air and contaminant vapor flow toward an extraction well. The extraction well becomes a point source for off-gases, which can either be vented to the atmosphere or treated. In positive pressure systems, air is injected into the subsurface to induce air flow toward the soil surface. Positive pressure systems may have advantages with regard to treatment efficiency by moving VOCs and oxygen through the microbially active rhizosphere. Fugitive VOC emissions from positive pressure bioventing systems, however, may pose health and regulatory concerns and can overstate the effectiveness of the bioventing process. Air emissions can result from incomplete mineralization of biodegradable compounds or from volatilization of compounds such as tetrachloroethene (PCE) which are not degraded under the given conditions.

The fate of VOCs was considered during a bioventing treatability study conducted at the former Plattsburgh Air Force Base (PAFB)¹. Over a period of four decades, fire training exercises were conducted at PAFB. During these exercises, bermed fire training pits were filled with water, jet fuel and spent solvents. The mixture was then ignited and extinguished. Unburned fuel migrated into the subsurface resulting in soil and groundwater contamination. The site is currently being remediated as part of the base closure process.¹

Methods of measuring surface emissions from hazardous waste remediation sites include: 1) an inversion algorithm that relies on downwind measurements;² 2) remote sensing methods that utilize differential absorption Light Detection and Ranging (LIDAR), Fourier Transform Infrared (FTIR), and ultraviolet (UV) sensors to quantify emissions; and 3) an emission isolation flux chamber (EIFC) method.³ The inversion algorithm method relies on downwind measurements of contaminants in order to back calculate total emissions. While this method can be accurate, it only works under steady wind and near neutral atmospheric conditions. Since meteorological conditions can not be known beforehand at the site, this method was not considered further in this project. Remote sensing methods, while accurate under most atmospheric conditions, are expensive and were therefore discounted.

The method that was considered to be the most applicable to the site given the budgetary constraints, site conditions and the scope of the proposed research was the EIFC method. In addition, a second method which uses a soil gas profile of the rhizosphere was developed by the authors to calculate emissions. This paper presents the results of an evaluation of the proposed methods for determining soil surface flux of VOCs. Specific objectives include: 1) evaluation and modification of EIFC for direct measurement of surface emissions; 2) development of a soil gas profiler (SGP) for near surface soil gas sampling; 3) testing of the EIFC and the SGP in a mesoscale bioventing system (MBS) using a conservative tracer; and 4) application of a mathematical model of contaminant transport and surface flux to the mesoscale system.

The EIFC method uses a modified version of a design developed for the EPA.³ The EIFC allows a direct measurement of VOC flux from the soil. Sampling is performed at randomly selected points on a grid superimposed over the contaminated zone. The EIFC method was previously used to monitor

emissions at the site, however, data obtained showed a high degree of variability. The high variability may have been due to spatial variation in the emissions or to the inappropriate use of the EIFC, which was developed to measure emissions caused by diffusion (passive flow) and not by advection (forced flow) as in bioventing. For this study, the EIFC collection method was modified from the EPA design to compensate for advective flow.

The SGP permits the extraction of small volume samples of soil gas at regular intervals from ground level to 45 cm below the surface. Soil gas profiler data is used to calibrate a model of contaminant fate and transport. An estimation of contaminant flux at the soil/atmosphere interface is calculated from the calibrated model.

THEORETICAL DEVELOPMENT

A simple analytical model of the transport of a conservative tracer through a soil column is presented in this section. In addition, a mass balance over an EIFC is presented.

Transport Model

A simple analytical model of transport was used to describe the flux of a conservative tracer through a mesoscale bioventing system (MBS). The porous media was assumed to be homogeneous and isotropic and the mass flux was assumed to be constant. Sorption and chemical and biological reactions were also assumed to be insignificant. A balance of mass flux, diffusion, and advection yields the differential equation shown as Equation 1.

$$J = vC_z - \theta_a D^* \frac{dC_z}{dz} \quad (1)$$

where

- J = Tracer flux ($\mu\text{g m}^{-2} \text{s}^{-1}$)
- C_z = Tracer concentration ($\mu\text{g m}^{-3}$)
- v = Specific discharge (m s^{-1})
- D^* = Effective diffusion coefficient, constant ($\text{m}^2 \text{s}^{-1}$)
- θ_a = Air-filled porosity, constant (dimensionless)
- z = Vertical distance (m)

A schematic of the MBS, indicating the direction of tracer flow, is shown in Figure 1. Imposing the boundary condition of $C = 0$ at $z = 0$ (assuming the tracer is swept away from the surface), Equation 1 can be solved analytically to yield C as a function of z . The analytical solution is shown as Equation 2.

$$C_z = \frac{J}{v} \left[1 - \exp\left(\frac{vz}{\theta_a D^*}\right) \right] \quad (2)$$

Equation 2 can be calibrated using measured concentration profiles to yield a mass flux if the specific discharge and air-filled porosity are known and an effective diffusion coefficient is assumed. Solving for flux at the plenum ($z = -L$), a contaminant flux based on plenum concentration can be obtained as shown in Equation 3.

$$J_p = \frac{vC_p}{1 - \exp\left(-vL/\theta_A D^*\right)} \quad (3)$$

where

- C_p = Tracer concentration in plenum ($\mu\text{g m}^{-3}$)
 J_p = Mass flux estimation based on plenum concentration ($\mu\text{g m}^{-2} \text{s}^{-1}$)

The effective diffusion coefficient, D^* , describes the diffusive mass transport of a compound through a porous matrix. Millington⁴ developed a model to describe the effects of a multiphase porous media (solid-liquid-gas) on a compound's theoretical binary diffusion coefficient⁵. The Millington model, which yields an effective diffusion coefficient, is shown as Equation 4.

$$D^* = D_{AB} \frac{\theta_A^{7/3}}{n^2} \quad (4)$$

where

- D_{AB} = Theoretical binary diffusion coefficient
 n = Soil porosity

An estimate of D_{AB} ^{6,7} (helium into air) was used in conjunction with the Millington model for D^* . This predicted diffusion coefficient was used in calibrating the transport model (Equation 2).

Emission Isolation Flux Chamber

A schematic of the EIFC is shown in Figure 2. The EIFC approach to the measurement of soil gas emissions is dependent upon the mixing characteristics of the isolation chamber.³ A clean sweep air is introduced to the chamber of the EIFC which causes it to behave like a continuous flow stirred tank reactor (CFSTR), meaning that the concentration of trace gases in the chamber equals the concentration at the outlet. By measuring the exit gas concentration, the surface emissions can be calculated from a simple mass balance. The mass balance is given by Equation 5.

$$V \frac{dC}{dt} = Q_{sg} C_{sg} + JA_E - (Q_{sg} + vA_E)C \quad (5)$$

where

- C = Measured concentration of contaminant at the outlet ($\mu\text{g m}^{-3}$)
 Q_{sg} = Sweep gas flow rate ($\text{m}^3 \text{s}^{-1}$)
 C_{sg} = Concentration of contaminant in sweep gas ($\mu\text{g m}^{-3}$)
 A_E = Surface area enclosed by the flux chamber (m^2)
 V = Volume of the EIFC (m^3)
 v = Specific discharge of contaminant (m s^{-1})
 J = Surface flux of contaminant ($\mu\text{g m}^{-2} \text{s}^{-1}$)

Imposing the boundary conditions of $C = 0$ at $t = 0$, Equation 5 can be solved to yield the concentration in the chamber as a function of time. This solution is shown as Equation 6.

$$C = C_{ss} \left[1 - \exp\left(-t/\tau\right) \right] \quad (6)$$

where

C_{ss} = Steady-state contaminant concentration in EIFC ($t \rightarrow \infty$)

t = Time

$\tau = V/Q_{sg}$

Assuming pure sweep gas ($C_{sg} = 0$) and steady-state conditions, Equation 5 can be solved for the surface flux:

$$J = (Q_{sg} + vA_E)C_{ss}/A_E \quad (7)$$

MATERIALS AND METHODS

Experiments were performed at the University of Massachusetts, Amherst, Environmental Engineering laboratories. All experiments were conducted using helium as a conservative tracer. Future work will include mesoscale evaluation of VOC emissions from an actively biodegrading system.

Mesoscale Bioventing System

The MBS, shown in Figure 1, consisted of an anodized aluminum box (61 cm by 61cm by 46 cm high) packed with soil. Underlying the 25.4 cm of soil were 2.5 cm of pea gravel, a perforated plate and plenum chamber which together allowed for the introduction of air and an inert tracer gas at a known concentration. Air was supplied by an oilless compressor, and flow rates of both the air and tracer were controlled with flow meters. Air entering the MBS was humidified to maintain a constant soil moisture content.

Soil in the MBS was a uniform sand packed to a bulk density of approximately 1.6 g cm^{-3} . A porosity of 0.39 was calculated from the bulk density, a measured moisture content of 2.6% by weight, and a grain density of 2.65 g cm^{-3} .

Soil Gas Profiler

The soil gas profiler (SGP), shown in Figure 3 was designed to extract 250 μL soil gas samples while minimizing impact to the soil and adjacent soil gas. The SGP was constructed using narrow bore stainless steel tubing (24 in x 0.0625 in OD, 0.010 in ID). Total probe dead volume was 36 μL . A 40 μm sintered stainless steel filter element (Mott Metallurgical Corp.) was attached at the gas inlet end and a zero dead volume union (Valco) acted as a sampling port. The narrow bore tubing was inserted into 0.25 inch ID stainless steel tubing for structural rigidity. The narrow bore tubing and protective sheath were joined with brass compression fittings (Swagelok®). The filter element was crimped on to the narrow bore tubing and sealed to the stainless steel sheath with silicone caulking, ensuring that the gas was pulled only from the surrounding soil. A Teflon™ faced septa (0.125 in OD) was pressed against the ferrule inside the union to provide a sampling port for a syringe needle.

The SGP was hand-pushed into the soil to the desired sampling depth. A gas-tight syringe (Hamilton) was used to purge 50 μL of gas from the probe before a 250 μL sample was taken. The septum on the SGP sampling port was replaced after every three samples.

Emission Isolation Flux Chamber

The EIFC built for this research was based on an EPA design, and was modified for the purpose of this project. All of the EIFC materials which come in contact with either the sweep gas or ground emissions are either stainless steel or Teflon™, except for the acrylic dome. The base of the EIFC consisted of an 18 cm high, 41 cm internal diameter stainless steel cylinder. A 51 cm outside diameter stainless steel flange was welded to the top of the cylinder. The dome was attached to the flange by 20 bolts, and it was held in place by a 51 cm OD aluminum flange. A Gore-tex™ gasket was used to make an air tight seal between the dome and the steel flange.

Five stainless steel ports were provided through the base of the EIFC. One port was used to provide access for a temperature probe, one for a pressure gauge, one as an inlet port to provide sweep air, one as an outlet port, and the last one was reserved as an auxiliary port.

The main EIFC modifications for this study were similar to those made by Dupont⁸ and consisted of the addition of a gas sampling pump (SKC) at the EIFC outlet port and a magnehelic pressure gauge (Dwyer, -0.05 to + 0.20 inches wc). This allowed for fine control over pressure drop (maintained at zero in wc) across the EIFC.

Soil Gas Sample Analysis

All gas samples from the MBS, the EIFC, and the SGP were analyzed isothermally (50 °C) using a Varian 3700 gas chromatograph (GC) equipped with a 3.05 m, 0.6 cm Porapak-Q packed column, a thermal conductivity detector (TCD) and a Varian 4270 integrator. The TCD was operated at a temperature of 220° C with a current at 78 mA, and a filament temperature of 290° C. Nitrogen was used as a carrier gas at a flow rate of 25 mL min⁻¹. Quality control included standards during each sampling period and duplicates of EIFC and plenum samples. Duplicates of SGP samples could not be obtained. All gas samples (250 mL) were collected with gas-tight syringes.

Experimental Program

A set of experiments was conducted to determine EIFC performance. Initial tests were performed with the bottom of the chamber sealed by an acrylic sheet and a gasket. An inert tracer or smoke was introduced into the EIFC. A vacuum pump (SKC) was attached to the EIFC outlet port to maintain zero gauge pressure in the chamber.

EIFC emission sensitivity to benzene was also evaluated. With the bottom of the EIFC sealed, benzene was introduced to maintain a 10 ppb_v concentration in the EIFC. Benzene contaminated EIFC gas (160 mL) was pulled across adsorbent tubes (packed with Carbotrap™ B and Carbosieve™ S-III). The tubes were desorbed with an Envirochem Unacon Series 810 capillary inletting system and analyzed with a Varian 3300 GC equipped with a flame ionization detector.

Experiments to determine helium flux from the MBS were conducted at three different specific discharges (0.0020, 0.0052, and 0.0067 cm s⁻¹), with $n = 0.39$, $\theta_A = 0.35$, and $L = 0.29$ m. Plenum helium concentration was maintained at approximately 10,000 ppm_v throughout the experiments. Immediately prior to soil gas sampling, the plenum concentration and gas flow rates were measured three times to establish a mass flux. Plenum concentrations were also measured several times during the sampling period to ensure that mass flux remained constant.

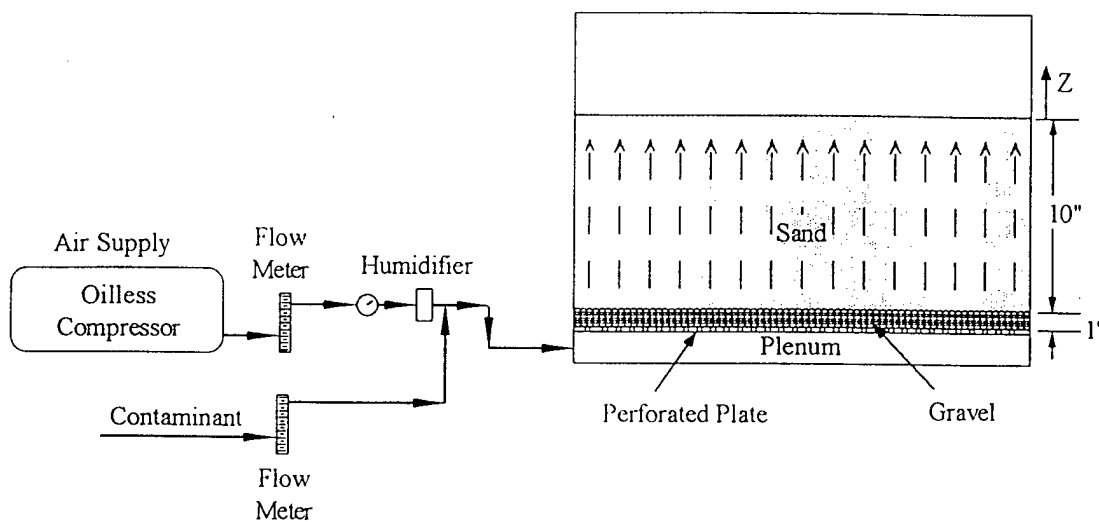


Figure 1: Mesoscale Bioventing System

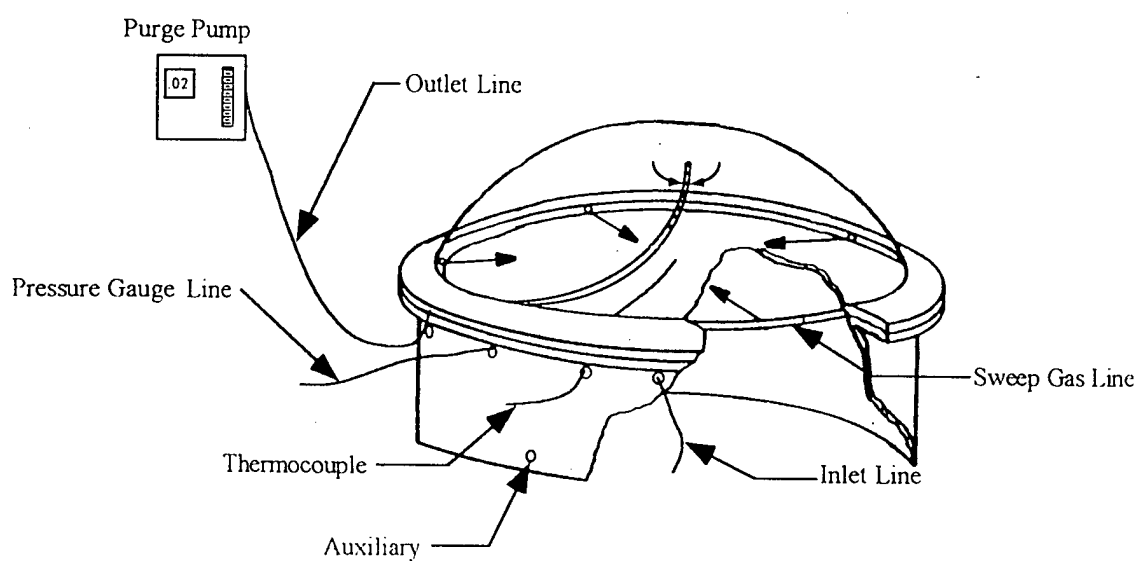


Figure 2: Isolation Flux Chamber

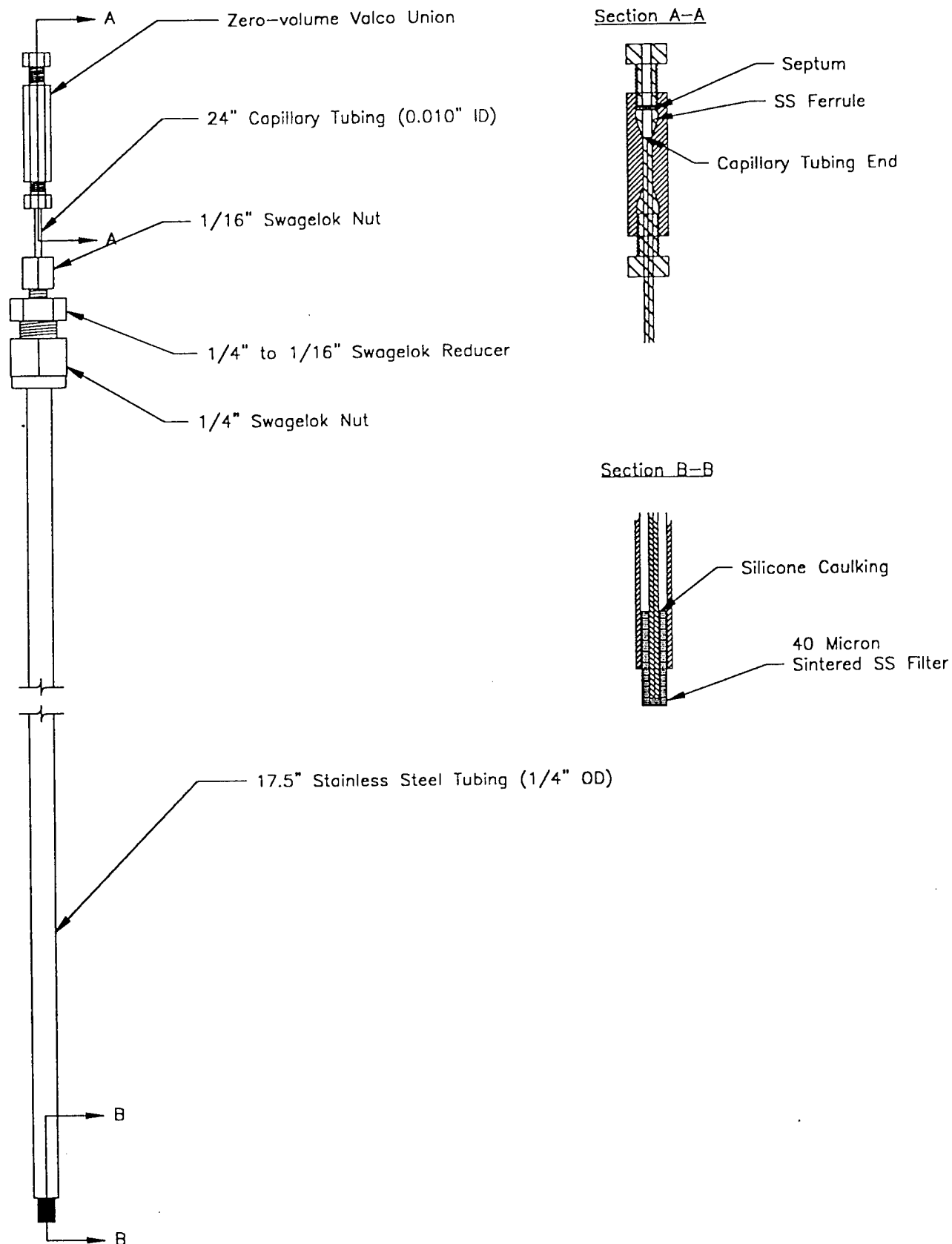


Figure 3: Soil Gas Profiler

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Table 1: Comparison of EIFC Measured and SGP Calibrated Mass Flux.

| | $v = 0.0020 \text{ cm/s}$ | $v = 0.0052 \text{ cm/s}$ | $v = 0.0067 \text{ cm/s}$ |
|--|--|--|--|
| | J | J | J |
| | ($\mu\text{g}/\text{m}^2 \text{ s}$) | ($\mu\text{g}/\text{m}^2 \text{ s}$) | ($\mu\text{g}/\text{m}^2 \text{ s}$) |
| Plenum-Based Flux (J_P) ^a | 96 | 126 | 185 |
| EIFC Measured Flux | 74 | 99 | 151 |
| SGP Calibrated Flux ^a | 72 | 116 | 177 |

a. $D^* = 0.36 \text{ cm}^2/\text{s}$ obtained using Millington⁴ prediction and the Fuller *et al.*¹⁰ estimate of D_{AB}

Table 2: Minimum Detectable Emission Rate for Benzene

| | SGP Method | Modified EIFC Method | EIFC Method ^a |
|--|----------------|-------------------------|--------------------------|
| Minimum Detectable Flux ($\mu\text{g}/\text{m}^2 \text{ min}$) | 4 ^b | 1.3 ^c | 1.2 ^c |

a. Kienbusch³

b. Estimation based on 250 μL sample (100 ppb_v benzene detection limit)

c. Estimation based on 10 ppb_v benzene concentration in EIFC

Surface emissions from the MBS were measured with the EIFC at various times throughout each sampling session. Helium concentrations were allowed to reach steady-state inside of the EIFC before sampling. A sweep gas flow of 3.8 L min^{-1} and a chamber pressure of zero gage in the EIFC were maintained in all experiments. Soil gas profiles were obtained at 3-5 random locations with the SGP for each mass flux. Soil, EIFC, and ambient temperatures were monitored with thermocouples. EIFC and soil temperatures were used to convert concentrations from a volumetric to a mass basis using the ideal gas law.

RESULTS

Emission Isolation Flux Chamber Evaluation

A smoke test was performed to visually observe mixing characteristics inside the chamber. For this experiment, a 1 L syringe was used to draw smoke from a smoke source. The smoke was then injected through the bottom of the chamber. This test allowed for visual verification of uniform mixing throughout the chamber.

A second test consisted of a tracer study to determine the time required to achieve steady state conditions in the EIFC and to quantitatively determine its mixing characteristics. Zero grade helium was injected through the bottom of the chamber. Samples were taken starting at the time the tracer was introduced into the chamber and at three minute intervals until steady state was achieved. Steady state was determined to be achieved when the concentration of helium inside the EIFC was 90 percent of the expected steady state concentration.

EIFC mixing characteristics were determined by comparing chamber concentration as a function of time to the theoretical values (Equation 6) expected in a CSTR. A comparison of the measured concentrations at various times inside the EIFC to those predicted for an ideal CFSTR is shown in Figure 4.

Experiments were performed at sweep gas flows from 1 to 5 L min^{-1} . The recovery at all flow rates was greater than 90% after steady state was achieved. However, as sweep gas flow decreased, the time required to achieve steady state increased from less than 20 min at a flow rate of 5 L min^{-1} to greater than 90 min at a flow rate of 1 L min^{-1} . The longer times are impractical for field work because of the large number of samples that must be taken. Low sweep gas flows also had a negative impact on the mixing regime.

Based on the time to steady state and on mixing characteristics, a working flow rate of between 3.5 and 4 L min^{-1} was chosen. This flow range provided a compromise between sampling time (under 27 minutes) and sample dilution. Low sweep gas flows are attractive because of sample dilution at higher flows, especially in the field where gas concentrations are usually low.

Tracer Flux Evaluation

To evaluate the performance of the EIFC and SGP, both methods were used to measure three known tracer fluxes through the MBS. The tracer concentration profiles were used to calibrate the transport model by using mass flux as the calibrating parameter. A single parameter Fibonacci iterative search program was used to minimize the mean absolute error between measured and calibrated concentrations. Tracer concentration profiles for the three mass fluxes tested and model calibrations are shown in Figures

5 through 7. Model calibrations fit the profile data well for all fluxes tested with a mean normalized error ranging from 3.9 to 6.3% for each data set.

Flux calibrations and flux measurements derived from the EIFC results are compared to the plenum-based estimation of mass flux in Table 1. The results show that the SGP data and calibration underestimated J_p by 4 to 25%. The EIFC underestimations ranged from 18 to 23%. For both methods there is a trend toward under estimating mass flux at low MBS flux. A possible explanation of this trend is the non-linear response of the thermal conductivity detector at low helium concentrations. Calibration curves used in analyzing gas samples may not have been applicable to the concentrations in the MBS at the lowest flux. This may have led to the underestimation of flux.

A comparison between minimum emission rates of the methods under investigation is shown in Table 2. The SGP method was estimated to measure a minimum benzene flux of $4 \mu\text{g m}^{-2} \text{min}^{-1}$. This estimation assumes benzene vapor transport by diffusion with an effective diffusion coefficient $D^* = 0.043 \text{ cm}^2 \text{s}^{-1}$. D^* was calculated using the Fuller *et al.*¹⁰ estimation of D_{AB} and a conservative Millington⁴ correction of 0.5 for diffusion through porous media. The SGP estimation also assumes that the 250 μL sample was taken at 2.5 cm below the surface. The emission sensitivities of the modified EIFC method and the EIFC method presented by Kienbusch³ are 1.2 and 1.3 $\mu\text{g m}^{-2} \text{min}^{-1}$, respectively. These values compare favorably to the $4 \mu\text{g m}^{-2} \text{min}^{-1}$ calculated for the SGP method.

CONCLUSIONS

Both the EIFC and the SGP methods are useful for calculating the flux of VOCs at bioventing sites. The EIFC had to be modified by the addition of a vacuum pump and a pressure gauge when monitoring advective flow systems to minimize negative biasing⁹. Optimum sweep gas flow rate was determined to be between 3.5 and 4 L min^{-1} to balance time to steady state and sample dilution.

The SGP method was found to give comparable flux estimates to those given by the EIFC method. The SGP was also found to have some advantages over the EIFC. These include faster sampling time and the ability to obtain real time results without cryogenics or carbon tube trapping. However, the SGP is limited to small sample volumes to avoid disturbing adjacent soil gas.

Another drawback to the SGP method is its dependence on effective diffusivity and the assumptions of the model (e.g. zero gas concentration at the surface). Both methods were limited by GC detection limits, but the EIFC method can overcome this limitation by cryogenic or sorbent tube trapping methods.

FUTURE WORK

Future work will consist of fine tuning both methods, especially in regard to method detection limits, and repeating the work with VOCs in a biologically active MBS.

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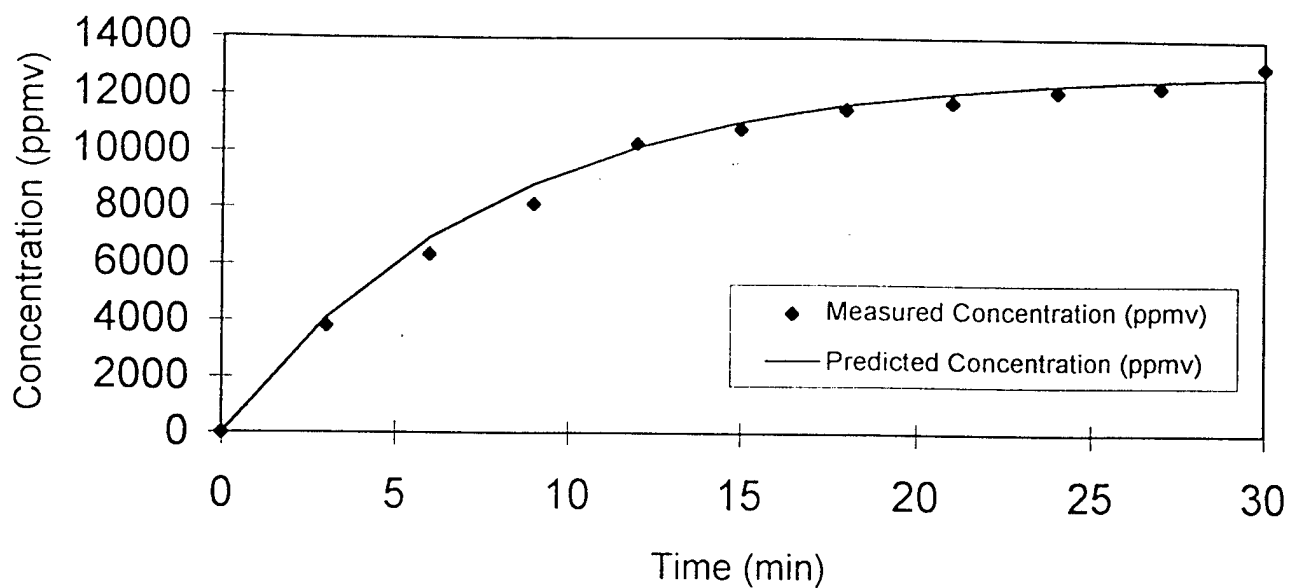


Figure 4: Comparison of Predicted to Measured Concentrations

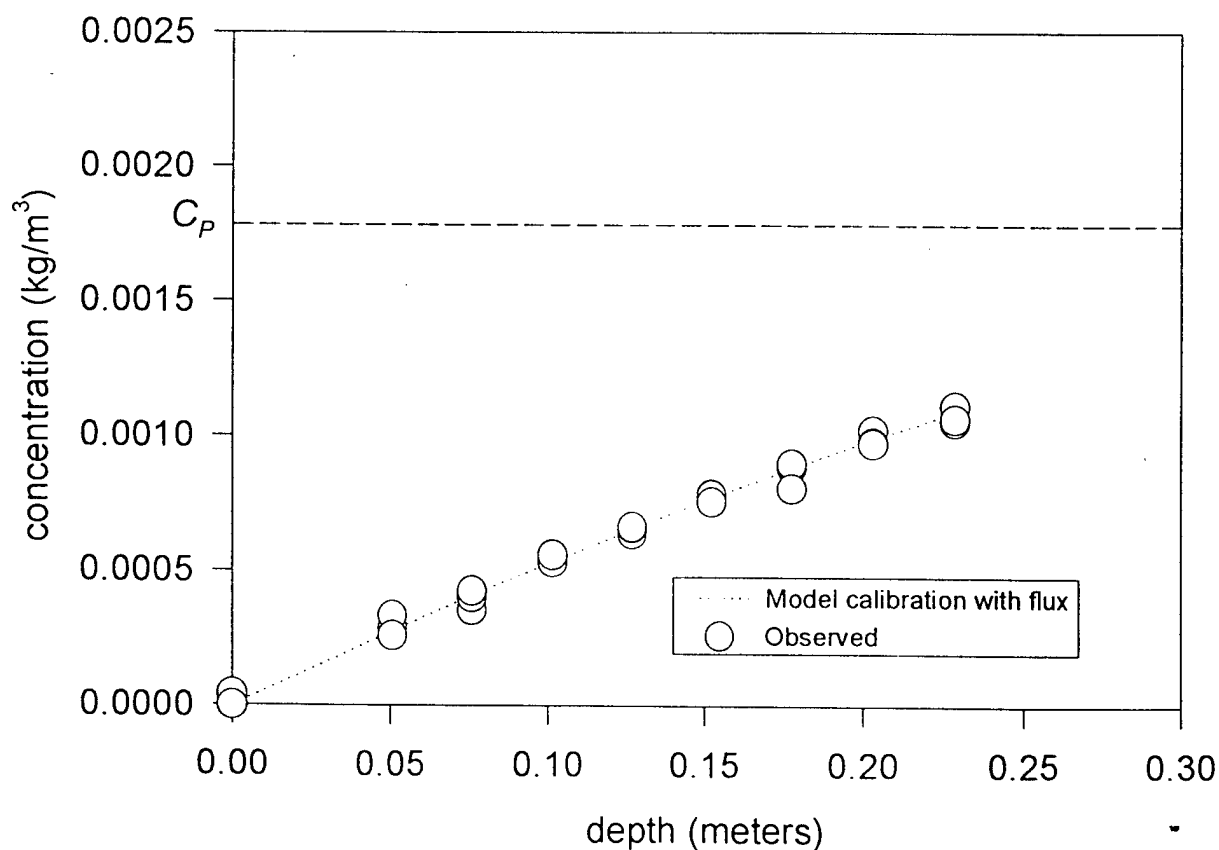


Figure 5: Concentration Profile For Mesoscale Bioventing System, $v = 0.0020$ cm/s.

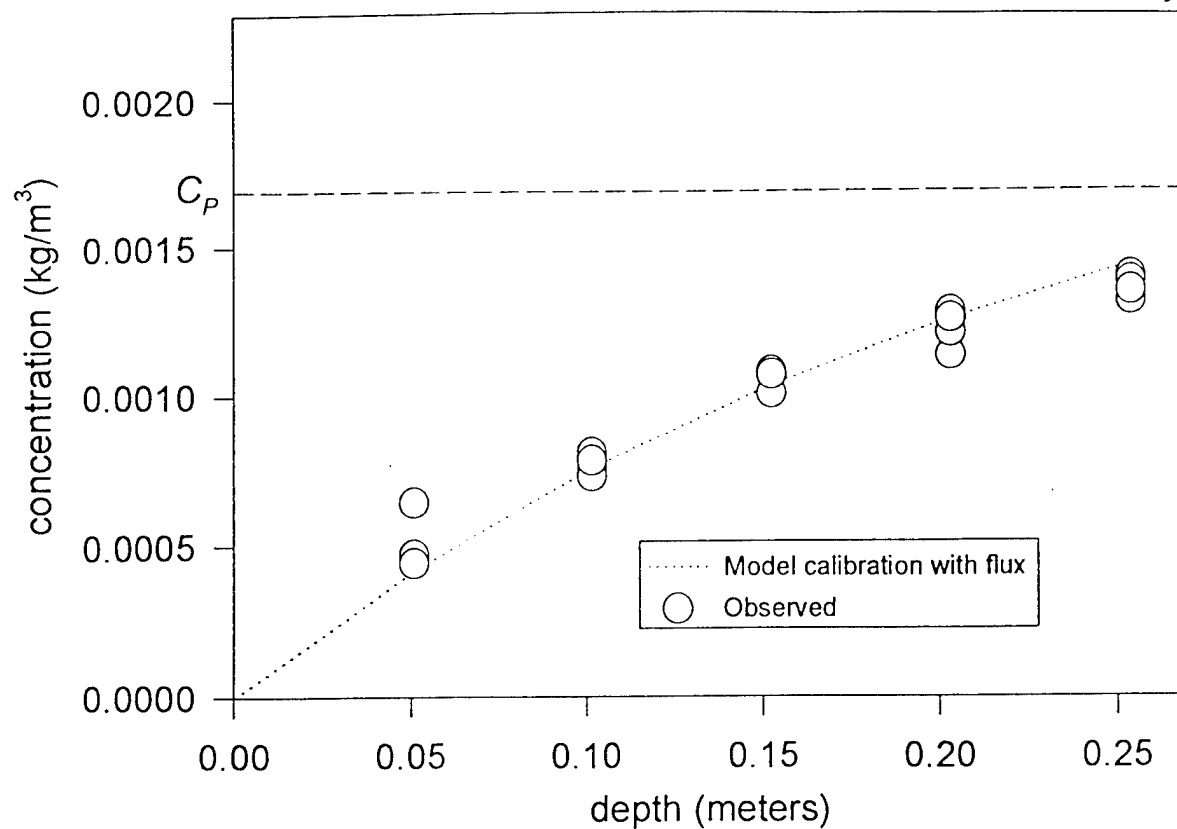


Figure 6: Concentration Profile For Mesoscale Bioventing System, $v = 0.0052$ cm/s.

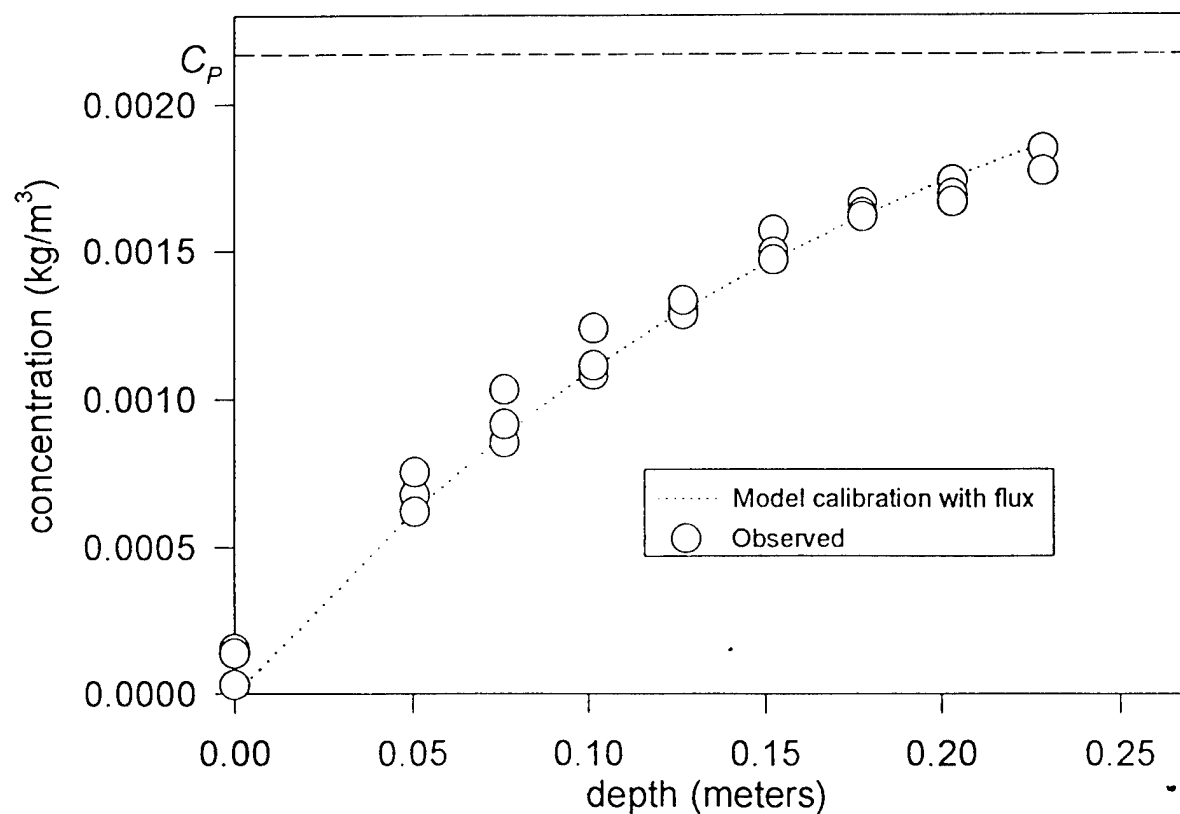


Figure 7: Concentration Profile For Mesoscale Bioventing System, $v = 0.0067$ cm/s.